Your Pain Is Not My Gain: How the in-utero Experience of Piglets Born From Sows With Lameness Shapes Their Life Trajectory

Marisol Parada Sarmiento (mparadasarmiento@unite.it)
University of Teramo
Thiago Bernardino
Universidade de São Paulo
Patricia Tatemoto
Universidade de São Paulo
Gina Polo
University of La Salle
Adroaldo José Zanella
Universidade de São Paulo

Research Article

Keywords: Aggression, animal welfare, prenatal stress, novel object test, open field test, vocalization

Posted Date: February 25th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-242331/v1

Version of Record: A version of this preprint was published at Scientific Reports on June 22nd, 2021. See the published version at https://doi.org/10.1038/s41598-021-92507-2.

Abstract

Experiences during gestation can alter the mother's behavior and physiology, affecting the development of the offspring, including the organization of their brains and emotional system. In livestock, one common challenge for pregnant animals is lameness: a multifactorial condition that causes pain, stress, and compromises welfare. Since pain experienced during gestation can affect offspring development, we aimed to quantify the emotional outcomes of 156 piglets born from sows with lameness during pregnancy. Gait scores of 22 pregnant group-housed sows were assessed six times at two-week intervals. Lameness scores varied from 0 (no lameness) to 5 (most severe lameness score). Saliva samples and behavior were assessed in the sows throughout the pregnancy. Sows were moved to individual farrowing pens and placental tissue was collected for glucocorticoids assessment. At 28 days of age, piglets were weaned, weighed, and grouped by body size and sex. Skin lesions were counted in each piglet on days 28, 29, and 30 after birth. During open field and novel object tests the vocalization and activity levels were evaluated. Piglet data were grouped by the lameness score of the sows as G1 (lameness score 0-1), G2 (lameness score 2-3), and G3 (lameness score 4-5). Data analysis included ANOVA or Kruskal-Wallis tests and pairwise comparisons were performed using Tukey and Kramer (Nemenyi) test with Tukey-Dist approximation for independent samples. G2 piglets were heavier than G3 at weaning. G1 piglets had fewer skin lesions at days 28 and 29 than G2 piglets. Moreover, G1 piglets vocalized more than G2 when they were subjected to the combined open field and novel object test. We did not identify differences in the concentration of placental or salivary glucocorticoids among the sampled sows showing different lameness scores. Lameness in pregnant sows has negative effects on the offspring, affecting weight gain, increasing aggressiveness, altering vocalization during an open field, and novel object tests in piglets.

1. Introduction

Lameness in pregnant sows is a common and painful condition and is one of the more frequent reasons for culling, causing considerable economic losses [1,2]. Lameness is categorized as the most reliable indicator of animal welfare in pigs along with tail injuries, and therefore it is recognized as a key indicator of animal welfare [3]. Lameness can be the consequence of several factors including inadequate handling, improper housing conditions, and deficient nutrition. High animal density in poor conditions can also trigger lameness which can be caused by post-mixing aggression [4]. Furthermore, nutritional factors as mineral and vitamin deficiencies may be detrimental to bones, articular cartilages, and hoofs [5]. Additionally, lameness can cause health, behavioral, and physiological alterations. The main health impairments of lameness in sows include traumas, fractures, osteochondrosis, and foot lesions [1]. Behavioral modifications involve a decrease of social interaction, exploratory behavior [6], and alteration in feeding and lying behavior [7,8].

Pain can be defined as [an unpleasant sensory and emotional experience associated with actual or potential tissue damage] [9]. A painful stimulus is related to the sympathetic nervous system and the hypothalamic-pituitary-adrenal axis (HPA), and it can be assessed by measuring the production of glucocorticoids [10]. Because of this, pain is considered a stressful condition, which during pregnancy could affect fetus development, mediated by high glucocorticoid concentration. The main placental protective system against active and high glucocorticoid levels is the placental enzyme 11 beta-hydroxysteroid dehydrogenase (11β-HSD-2), responsible for the inactivation of the bioactive glucocorticoid cortisol by conversion to cortisone; a failure in this system has negative consequences in fetal programming [11]. Moreover, pain can influence the release of cortisol, adrenocorticotropic hormone (ACTH), adrenaline, and noradrenaline, and even affect the cardiovascular system, varying heart rate, blood pressure, and tissue perfusion [12].

The circadian pattern of cortisol is indicative of good functioning of the hypothalamic-pituitary-adrenal axis in pigs. The disruption in circadian cortisol patterns in sows with compromised welfare was reported by [13]. The effects of high levels of prenatal glucocorticoids on the offspring have been studied in several species. In humans, rodents, and rhesus monkeys, high levels of prenatal glucocorticoids increase the risk of neuropsychiatric disorders, producing changes in the size of the hippocampus and behavioral disorders in offspring [14,15]. In late pregnancy, the effects are related to a reduction of hippocampal volume, neuronal number, and activity of placental 11β-HSD-2, generating an impact on emotional states [16,17]. In pregnant sows, the administration of high levels of ACTH (an adrenocorticotropic hormone involved in the regulation of cortisol) has demonstrated an increase in salivary and plasma cortisol concentration and a reduction in the length of gestation [18]. Furthermore, it has been shown that periodic isolation, high cortisol concentration, or the experience of chronic hunger in sows alters outcomes in the offspring, such as body weight, basal cortisol concentration, HPA stress responsiveness, brain neurotransmitters, and aggressive behavior [16,19]. In this context, we aimed to quantify the emotional and performance outcomes in offspring born from lame sows. We hypothesized that offspring born from sows with lameness during pregnancy is emotionally less adapted for common challenges presented in the environment of commercial pig production and that therefore may present fear of novel situations or alterations in agonistic behavior, which can, in turn, affect performance indicators.

2. Results

2.1. Data from sows and offspring before weaning

To analyze salivary cortisol, the data were first observed in terms of the circadian rhythm. We measured morning and afternoon salivary cortisol concentrations of sows from the same group, and then comparisons were made between the G1, G2 and G3 grouped sows. The descriptive measures of saliva cortisol, placental cortisol/cortisone, and performance data can be found in Supplementary Tables S1, S2, and S3, respectively.

On day 75 of pregnancy, we did not find differences between morning and afternoon salivary cortisol levels between the experimental groups (Wilcoxon test or T-test; $p > 0.05$; see Supplementary Table S1 for precise p-values). In addition, as expected, the absolute values of cortisol in the morning were higher than those in the afternoon for all groups. On day 90 of pregnancy, we found a difference between morning and afternoon salivary cortisol in groups G1 (T-test; $p = 0.045$) and G2 (T-test; $p = 0.004$), where the morning values were higher than in the afternoon. There was no difference in these values in the G3 group (Wilcoxon test; $p = 0.294$). There were no salivary cortisol differences between the G1, G2, and G3 groups in the morning or afternoon from the 75th to the 90th day of pregnancy (ANOVA One-way or Kruskal-Wallis test; $p > 0.05$).

No difference was found in placental cortisol and cortisone concentration between G1, G2, or G3 (One-way ANOVA test; $p = 0.681$ for placental cortisol, and $p = 0.457$ for placental cortisone), and in all groups, placental cortisone was higher than placental cortisol (see Supplementary Table S2 for details). Results of performance data were no different when compared between groups G1, G2, and G3 (see Table 5 for details).

2.2. Body weight and skin lesions in piglets

We did not identify any difference in birth weight between piglets from groups G1, G2, or G3 (Kruskal-Wallis test; $p = 0.558$). However, weight at 21 and 27 days old was different between the groups (One-way ANOVA test; $p = 0.000768$ for weight at 21 days old, and $p = 9.17e-06$ for weight at 27 days old). A box plot of the weight of the piglets at 21 and 27 days old can be found in Fig. 3. At 21st days old, piglets from group G3 were lighter than piglets from G1 (paired comparison Tukey test; $p = 0.0118$) and G2 (paired comparison Tukey test; $p = 0.00064$), while there was no difference between piglets from G1 and G2 (paired comparison Tukey test; $p = 1$). We found something similar with the weight at 27 days old. The piglets from group G3 were lighter than piglets from G2 (paired comparison Tukey test; $p = 8.7e-06$) and piglets from group G1 were lighter than piglets from G2 (paired comparison Tukey test; $p = 0.008$), while there was no difference between piglets from G1 and G3 (paired comparison Tukey test; $p = 0.146$; mean G1 = 8.394; mean G3 = 7.839).

Regarding the number of skin lesions, we found differences at day 28 and 29 (Kruskal-Wallis test; $p = 0.00331$ at day 28; $p = 0.026$ at day 29). The Fig. 4 is a box plot of the number of skin lesions of the piglets at 28 and 29 days old. On day 28, piglets from group G1 had fewer skin lesions than piglets from G2 (paired comparison Kramer's test; $p = 0.009$), and piglets from G3 had fewer skin lesions than piglets from G2 (paired comparison Kramer's test; $p = 0.021$). Additionally, we did not find a difference between piglets from group G1 and G3 (paired comparison Kramer's test; $p = 0.999$). On day 29 after farrowing, we identified fewer skin lesions in piglets from group G1 when compared with piglets from G2 (paired comparison Kramer's test; $p = 0.02$) and we did not identify any difference in the remaining comparisons (paired comparison Kramer's test; $p = 0.26$ for comparison between G1 and G3; $p = 0.70$ for comparison between G2 and G3). On day 30, no difference was found between groups (Kruskal-Wallis test; $p = 0.674$).

Descriptive measures about weight and skin lesions can be found in Supplementary Table S4.

2.3. Open field and novel object test

In the open field test we did not identify differences in latency (Kruskal-Wallis test; $p = 0.751$), activity (One-way ANOVA test; $p = 0.823$), access to lateral (Kruskal-Wallis test; $p = 0.931$) or central quadrants (One-way ANOVA test; $p = 0.374$). However, the number of vocalizations was higher in piglets from group G1 compared with G2 (One-way ANOVA test; $p = 0.044$; paired comparison Kramer's test; $p = 0.042$; see Fig. 5).

Similar to the results of the open field test, we found that there was only a difference in the number of vocalizations in the novel object test, with a higher number of vocalizations recorded in piglets from group G1 compared with G2 (Kruskal-Wallis test; $p = 0.00186$; paired comparison Kramer's test; $p = 0.001$; see Fig. 5). We did not see a difference in latency (Kruskal-Wallis test; $p = 0.884$), object exploration (Kruskal-Wallis test; $p = 0.641$), or proximity to novel objects (Kruskal-Wallis test; $p = 0.254$).

Descriptive measures from the variables analyzed during open field and novel object test can be found in Supplementary Table S5.

3. Discussion

In this study, we have tested the hypothesis that offspring born from sows with lameness, who experience pain during pregnancy, is affected by their in-utero and/or neonatal experience. Here we showed that lameness in pregnant sows has negative effects on the offspring, affecting weight gain, increasing aggressiveness, and altering vocalization during open field and novel object tests. We demonstrated that the weight on 21 and 27-day old piglets, total number of skin lesion, and vocalization events during a combination of open field and novel object tests were different when contrasting the offspring from sows which show no lameness, lameness, and severe lameness.

There were no differences in cortisol concentration between the groups in different stages of gestation. However, on day 90 of gestation, there was one difference between the saliva samples in the morning and afternoon in sows from G1 and G2, but not in G3. In the groups in which the difference was found (G1 and G2), the cortisol concentration was higher in the morning. The higher concentration in the morning has been related to circadian rhythms well established functioning, while in the afternoon a decrease is expected in a healthy system [20,21]. In the current study, lameness only affected circadian cortisol levels of severely lame sows (G3) on day 90 of pregnancy, since it was more concentrated in the afternoon than in the morning. No differences were found in placental cortisol and cortisone levels when contrasting non-lame and lame sows. Previous work [13] demonstrated that low ranking, poor welfare, group-housed sows had no circadian cortisol patterns. Data collected on day 90 of gestation is relevant as the animals, given their weight at the end of pregnancy, may experience more discomfort and pain as a result of lameness. In addition to salivary cortisol concentration, other measures could have been performed since lameness is a usually chronic condition [22], and could have affected inflammatory biomarkers [23,24]. Measurement of biomarkers of chronic stress could have given a more comprehensive view of the stress that lame sows experience.

It has already been reported in several species that an inadequate function of 11β-HSD-2 or high during pregnancy could decrease the weight and size of the offspring [25–28]. According to the results obtained from the analysis of cortisol and cortisone concentration in the placenta, the absence of difference between the sow groups (G1, G2, and G3) indicates that, possibly, the placenta was efficient in its role of protecting fetuses from maternal stress, mediated mainly by the action of the enzyme 11β-HSD-2 [11]. It is important to mention that sows were kept in groups during gestation, however, they farrowed in pens, and were kept in isolation, which may have affected the presence of glucocorticoid in placental tissue. These findings suggests that other mechanisms could be responsible for the changes found in the offspring of sows with or without lameness, such as placental gene expression. This could be affected by stressful situations and has the potential to alter fetal development [29], or the levels of embryo toxic cytokines present in inflammation events during pregnancy [30], as is the case of lameness.

Performance data before weaning were not affected by the sow lameness severity during pregnancy. In the case of prolificacy, lameness is not reported as a relevant factor that alters parameters such as the number of live piglets or other reproductive parameters in the sow [31]. However, curiously, weight at weaning was different between groups, in which it was lower in piglets G3 compared to G2. This result could have several explanations. We did not find evidence of a high concentration of glucocorticoids generated by the stress from pain in sows that could be released during gestation. The only evidence found was the disruption in the pattern of cortisol in the G3 group. More studies should be conducted to elucidate the causal mechanisms that may affect the performance of piglets. The glucocorticoids intervenes in a catabolic way in growth processes, and[14] in previous studies, where individuals have been treated with glucocorticoids during pregnancy, it was found that the offspring had lower weight at birth, compared with females that did not have treatment with glucocorticoids [32]. Another potential explanation of why these animals could have had less weight at weaning is nutritional. One of the possibilities is the metabolic costs associated with coping with lameness could have compromised the offspring during the prenatal and early postnatal period. Sows were fed individually, which meant that no competition for food could account for the lower body weight. The same applies to the feeding regime during lactation, which was identical for all the animals. When nutrition is poor during pregnancy, the metabolism of the fetus can be altered during the neonatal period. In addition to inadequate nutrition, the proper functioning of the enzyme 11β-HSD-2 is also affected, allowing then a greater passage of glucocorticoids to the fetus without prior inactivation [15,29], we did not measure glucocorticoids in placental tissue during pregnancy. In humans, those events that generate low weight at birth are associated with morbidity in adulthood [33], which leaves us with an open research window to conduct experiments that contemplate the monitoring of morbidity in animals born from females with a higher or lower degree of prenatal stress, especially lameness. The placental concentration of cytokines, which are released in response to inflammatory processes, during pregnancy appears to be higher in smaller pigs when compared with large animals [34].

Piglets at 27 days old from G3 were lighter than G1, while G1 piglets were lighter than G2. Interestingly, there was no difference in the data related to weight when all piglets in the litter were assessed. It is worth considering that the offspring after weaning were allocated according to the nutritional treatment of the sows, from the parallel experiment, which measured the impact of fiber in the diet [19] without mixing piglets from sows with different treatments (high or low fiber), and this interfered with the number of skin lesions in their offspring.

It was surprising to record a lower number of skin lesions in piglets from G1 than G2. This result indicated that piglets born from lame sows performed more aggressive interactions when compared with the offspring from sows with no lameness. Data on piglet aggression has been associated with compromised memory processes, resulting from the disruption of stress-responsive genes in the prematurely weaned pigs [35,36]. We did not measure whether memory processes varied between G1, G2, and G3. In periods of increased fetal sensitivity to glucocorticoids, the development of tissues and their organization can be compromised, in particular in the cardiovascular system, central nervous system, and metabolism [14].

Even though data were obtained from the same cohort of animals under the same condition, we had separate goals of analyzing the impact of a high fiber diet and the impact of lameness in the sows' offspring. No relationship was found between dietary fiber content [19] and lameness in the experimental sows. We evaluated differences in the proportion of sows being fed with high and low fiber diets between the lameness groups and no statistically significant difference was observed (Chi-squared test, p-value = 0.31). However, as there is no information related to the effect of fiber in the diet on the development of lameness, future studies are necessary to establish this relationship.

The vocalization during the fear tests was more frequent in piglets from G1 for both open field and novel object tests. The tests are recognized as fear tests, because they impose to the animals a novel and open area, in social isolation, and also to a novel object, so conflicting motivations such as avoidance and exploratory behavior can be measured [37]. Vocalizations are considered as an indicator of negative or positive emotions in different species, including domestic pigs [38–41]. In our results, is possible that the G1 group was more prepared to cope with challenging situations, as vocalization in piglets could have an evolutionary role when exposed to social isolation or situations that represent a negative emotional valence [42,43]. Nevertheless, it would be worth comparing vocalizations in piglets exposed to fear tests in other contexts to make a better comparison, also adding analysis of the acoustic characteristics of these vocalizations, to better analyze associated emotions. Moreover, a more detailed study on vocalization could offer a better understanding of the significance of this finding.

Data collection on skin lesions, vocalization, and weight were carried out independently from the measures of lameness during pregnancy. The data were analyzed after the completion of the study and animals were allocated to treatments by the first author, who did not have direct contact with the experimental animals.

To our knowledge, this is the first study investigating the lameness effects in sows during gestation and its outcomes on the offspring's welfare. Here we demonstrated that a high score of lameness in pregnant sows has negative effects on the offspring, affecting weight gain, increasing aggressiveness, and altering reactivity during fear tests, indicated by increased vocalization. Additionally, since there were no differences in the glucocorticoids in the peripheral system, as well as in the placenta tissues, probably other mechanisms, such as epigenetics, are involved in the outcomes we demonstrated, and this needs further investigation. Finally, it is worth emphasizing the relevance to ethical concerns to reduce the pain and suffering in the animals in our care especially in contexts where we have the knowledge to assess and mitigate, such as with lameness.

4. Material And Methods

4.1. Ethical approval

Data were collected from the experimental pig farm of the University of São Paulo (USP), located at the Campus Fernando Costa - Pirassununga, Brazil, with the approval of the Ethics Committee on the Use of Animals (CEUA) of the School of Veterinary and Animal Science (FMVZ/USP), with the number N° 3606300114, according to the Law 11.794, of October 8, 2008 and Decree 6899 of July 15, 2009 with the rules issued by the National Council for Control of Animal Experimentation (CONCEA) – Brazil.

The study was carried out according to the ARRIVE guidelines (https://arriveguidelines.org/). The approval of the ethics committee is placed as supplementary material.

4.2. Animals, facilities, and handling

Twenty-two pregnant sows (F1 Landrace + Large White) and their offspring were studied. The sows were nulliparous, healthy, and subsequently inseminated in the same period of the year with a pooled semen from a fixed group of commercial boars. After insemination and until the day 107th of gestation, the sows were group-housed in pens. Each pen had 3.3 m^2 of space per animal, nine individual feeding stations (1.8 m x 0.55 m), and *ad libitum* water supplied through nipple drinkers.

On the day 107th of gestation, the sows were moved from the group-housed pens to individual farrowing pens measuring 4.3 m x 2 m. Connected to the pen, there was a creep feeding area made of concrete (0.97m x 2.2 m), where piglets had unlimited access to the solid feed from birth. We kept all animals in the farrowing pens until day 28 of lactation. Bedding material was provided to the sows and piglets, composed of dehydrated sugarcane bagasse and hay. The farrowing was monitored with IP video cameras (Foscam®, Fi9821p HD 720P), with a real-time internet transmission to the experimenters. The delivery was followed through computers, smartphones, and direct observation. All sows were fed an identical solid lactation diet with *ad libitum* access.

The piglets were weighed on the 1st, 21st, and 27th days of age. In addition, during its first day of life, the routine management of the farm was carried out: teeth grinding, administration of iron dextran (100 mg, intramuscular), and identification with ear notch under local anesthesia with 5% lidocaine cream. Castration or tail docking was not performed. Weaning occurred at 28th days of age and the piglets were moved to the experimental pens (1 m x 0.75 m) with slatted plastic floors, provided with *ad libitum* access to feed and water, and daily cleaning.

4.3. Experimental design

To access the effects of lameness during the gestation of sows in the offspring, we assessed the lameness score of 22 sows, six times throughout gestation [44,45]. The behaviors of sows, salivary, and placental glucocorticoid concentration were analyzed [46]. In the offspring (N = 156 piglets), aggressiveness was assessed through skin lesion score and emotionality was assessed with a combination of open field and novel object tests [47]. An explanation of the experimental design can be seen in Supplementary Fig. S1 online.

4.4. Lameness assessment in sows

During gestation, six lameness assessments were performed with intervals of two weeks between them. The lameness score applied was a combination of two validated score systems (Table 1) [44,45].

According to the lameness score, sows were classified into three groups, G1: Sows with a degree of lameness ≤ 1 in all six lameness assessments. G2: Sows with a degree of lameness ≤ 3, with at least one of the six lameness assessments with degree 2 or 3. G3: Sows with a degree of lameness ≤ 5, with at least one of the six lameness assessments with degree 4 or 5.

The observation of lameness events of these sows was generated spontaneously throughout their gestation and pain treatment was performed according to the standard procedure (Flunixin Meglumine 2.2 mg/kg Intramuscular, once a day, for 4 days).

4.5. Pregnancy and farrowing

During pregnancy behaviors related to position and activity were collected on days 29, 30, 31, 59, 60, 61, 74, 75, 76, 89, 90, and 91, before and after feeding. Each animal was observed three times in each hour (pre and post-feeding, morning, and afternoon), for 6 minutes each, and totaling twenty-four minutes per day of observation. The behaviors observed were sleeping, lying ventrally, lying laterally, standing, sham-chewing, rooting the floor, rooting on the empty feeder, licking the floor, interacting with mats, and interacting with fences or gates. The details of each behavior are in Table 2.

Saliva samples were collected on the same days of behavioral assessment, early in the morning (06:00) and in the late afternoon (18:00). These samples were stored at -20º C immediately after collection and cortisol was measured with Enzyme Immunoassay (EIA) [48]. The collection methodology used was adapted from [49] and [50], using two hydrophilic cotton rolls tied to a dental floss with long tips and presented to each animal.

After farrowing, four placenta samples were collected in the same location and size at random from 19 sows and stored immediately at -20º C. Glucocorticoid extraction was performed to measure cortisol and cortisone levels using an EIA, as described by [48]. The placentas of three missing sows were not collected due to drawbacks.

Additional data were collected, such as pregnancy length, the total number of piglets born, total piglets born alive, total litter weight at farrowing, total litter weight at 21 and 27 days of age, average daily litter weight gain, average daily weight gain per animal and number of crushed piglets.

4.6. Post-mixing aggression score

Data from 156 piglets from the 22 sows were collected by the lameness sow group. The number and distribution of the individuals in each group are shown in Table 3. After weaning, piglets were distributed by weight and sex to create homogeneous groups, mixing individuals of two different litters per pen.

Through some skin lesions, post-mixing aggression was assessed, based on validated methodology [19,51]. Photographs and videos were taken daily from each piglet at 28, 29, and 30 days of age (see Fig. 1). Six piglets from each sow (three males and three females) were used for the evaluation of skin lesions. Two independent evaluators without prior knowledge of the origin of each piglet performed a manual count of skin lesions.

4.7. Open field and novel object test

A combination of open field and novel object tests were performed on 142 piglets at the end of 30 days of age using the methodology previously described [47], to assess the activity levels, exploratory behavior, and vocalization (Table 4). The tests were carried out in a pen with the floor marked with squares (see Fig. 2). To carry out the tests, the piglets were taken randomly, alternating between males and females. Due to unforeseen difficulties, the tests could not be done on all 156 piglets.

The open-field test consisted of positioning each piglet at the same starting point in the pen, in order to assess the time taken to move, time spent walking, and time remained in lateral or central squares. Followed by the open field test, the novel object test was carried out, which consisted of introducing an unknown object into the pen to assess latency, exploratory behavior, and proximity to the object. A yellow bucket with a capacity of 20 liters, empty, and made of polypropylene was used as an unknown object. To avoid visual contact between the piglets and the experimenter, a pulley mechanism was used to introduce the bucket in the pen. In both tests, all types of vocalization were counted. For each individual the tests lasted 10 minutes: 5 minutes for the open field test followed by 5 minutes for the novel object test. To reduce the possible chemical signals present in the environment, the pen was always washed with water between the animals and before the first piglet assessment.

Photographs and videos were used to assess skin lesions. Open field and novel object tests were recorded with a digital camera (Samsung WB250F Smart Wi-Fi Digital).

4.8. Statistical analysis

We used a Shapiro-Wilk test to determine the residual distribution of all variables (in sows: performance data, the concentration of saliva cortisol, and cortisol/cortisone placental concentrations. In piglets: skin lesion number, weight at 21 and 27 days of age, open field and novel object tests data,).

Depending on the distribution of the data, One-way ANOVA or Kruskal-Wallis tests were performed with a significance level of 5%. A paired comparison was made using Tukey and Kramer's test (Nemeyi). We performed the analyzes in the programming language R [52].

Declarations

Acknowledgments

To all students, professors, and staff involved in the University of Sao Paulo. Thanks to FAPESP for the regular FAPESP project (Processo FAPESP number 2018/01082-4), that provided partial funds for the development of this research. Additionally, TB was sponsored by FAPESP with Ph.D. scholarship (Processo FAPESP 2017/05604-2) during the preparation of this manuscript. To the University of Teramo in Italy by the Ph.D. scholarship granted to MPS during the preparation of this manuscript. The Brazilian pig farm TOPGEN for the supply of the experimental animals, Vedovati Pisos for the donation of the rubber mats used in the experimental work. Dr. Rupert Palme, Unit of Physiology, Pathophysiology and Experimental Endocrinology, Department of Biomedical Sciences, University of Veterinary Medicine, Vienna, has donated the reagents for the cortisol EIA.

Author contributions

MPS contributed to the writing of the manuscript, preparation of figures, analysis, and interpretation of data. TB contributed to data acquisition, interpretation of data, discussion of results, and preparation of Fig. 1. PT contributed to the data acquisition, interpretation of data, and discussion of results. GP contributed to the analysis of data, manuscript draft, and preparation of figures. AJZ contributed with the idea conception, design of the work, interpretation of data, and draft of the manuscript. All the authors contributed to the revision of the final version.

Competing Interests

The authors declare no competing interests.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Tables

Table 1

Locomotion score system to assess gait in sows adapted from [44,45].

Degree of lameness	Description
0	The animal moves easily with little stimulation and bears weight comfortably of all its legs.
1	Minor alterations in the gait. When standing, the sow alternates weight bearing in legs. It still walks easily.
2	Locomotor disturbance is perceptible in the gait, shorting the steps. Alters position and support of the legs when standing.
3	Supports the limb with difficulty. Shortened stride. Reluctant to bear weight on the affected limb.
4	Lameness of one or more limbs, display of compensatory behaviors such as arching of the back and/or squatting of the head. Reluctance to walk, difficult to move from one place to another.
5	Try to lie down, get up with difficulty and try not to support the committed leg(s).

Table 2

Sows behaviors collected on first, second and last third of gestation, before and after feeding. Adapted from [53].

Behavior	Definition
Sleeping	Sleeping animal
Lying ventrally	Lying with belly facing the ground with all limbs under the body
Lying laterally	Lying sideways, with all the limbs extended laterally
Standing	Body supported by the four limbs
Shame-chewing	Continuous chewing without the presence of visible food in the oral cavity
Rooting the floor	Snout touches the ground followed by head movements
Rooting on the empty feeder	Snout touches the empty feeder followed by head movements
Licking the floor	The tongue touches the floor and is followed by movements with the head
Interacting with mats	Snout or tongue touches mats followed by head movements
Interacting with fences or gate	Biting or nibbling the fence wire or gate

Table 3

The number (n) of sows and piglets studied per group

Group	Degree of lameness	Number of sows	Number of piglets
G1	0–1	7	52
G2	2–3	10	66
G3	4–5	5	38
Total	-	22	156

Table 4

Description of data collected during open field and novel object test.

Test	Measure	Description
Open field test	Latency	Time between piglet entering in the pen and walking
	Activity	Time spent walking
	Quadrants accessed	Time spent in central and lateral quadrants (quadrants on the edge of the pen)
	Vocalizations	A count of all types of vocalization
Novel object test	Latency	Time between the bucket being placed in the pen until animal interaction with the object (close to and with the head toward to the object)
	Near to the object	Time the animal spent close to the object (in quadrants that surround the object)
	Quadrants accessed	Time spent in central and lateral quadrants (quadrants on the edge of the pen)
	Vocalizations	Number of all types of vocalizations

Table 5
Results of performance data compared between groups G1, G2 and G3

Measure	Test	P value
Total number of piglets born	One-way ANOVA	0.493
Total number of piglets born alive		0.762
Total litter weight at 21 days of age		0.935
Total litter weight at 27 days of age		0.696
Average daily litter weight gain		0.413
Average daily weight gain per animal		0.746
Gestation length	Kruskal-Wallis	0.163
Total litter weight at farrowing		0.169
Number of crushed piglets		0.242

Figures

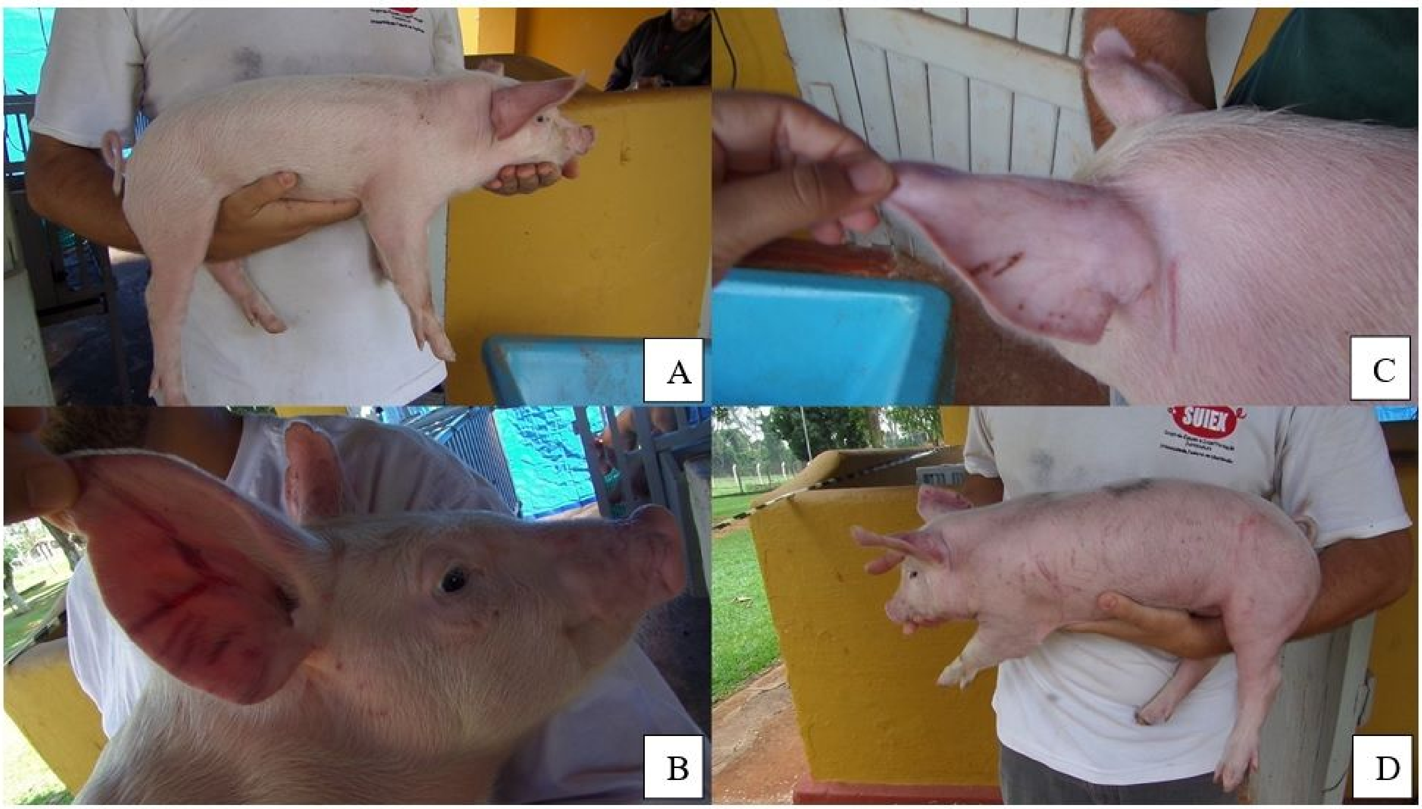

Figure 1

Examples of images used to count skin lesions. A: right lateral body; B: face and right lateral ear; C: back of the right ear and D: left lateral body19.

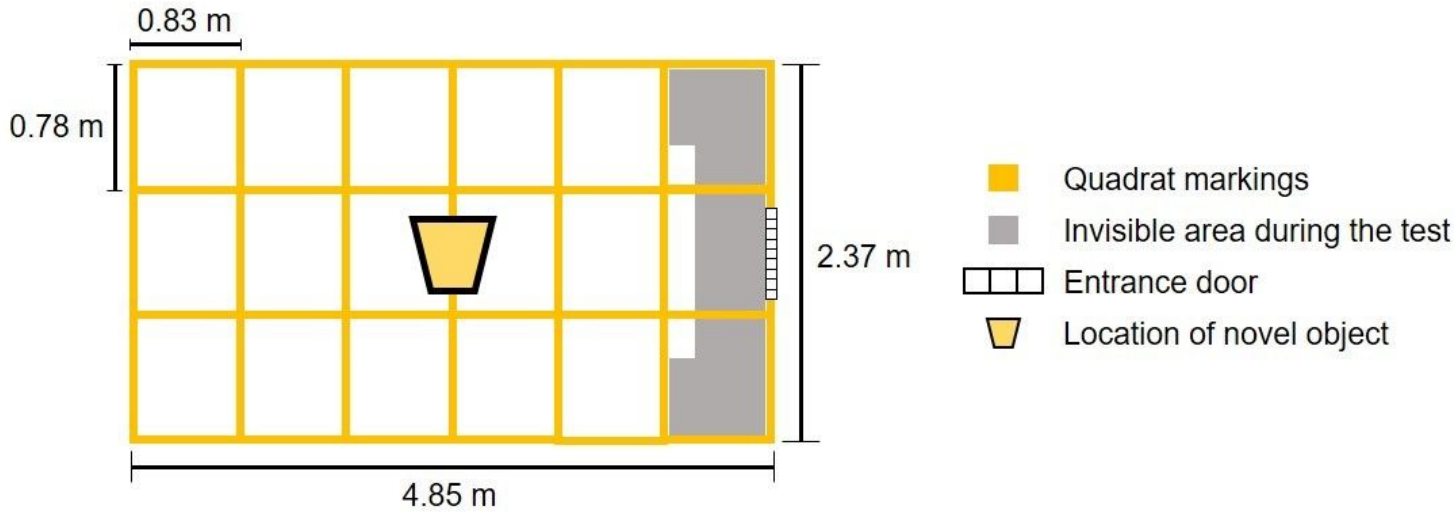

Figure 2

Graphic representation of pen used to perform the open field and novel object tests.

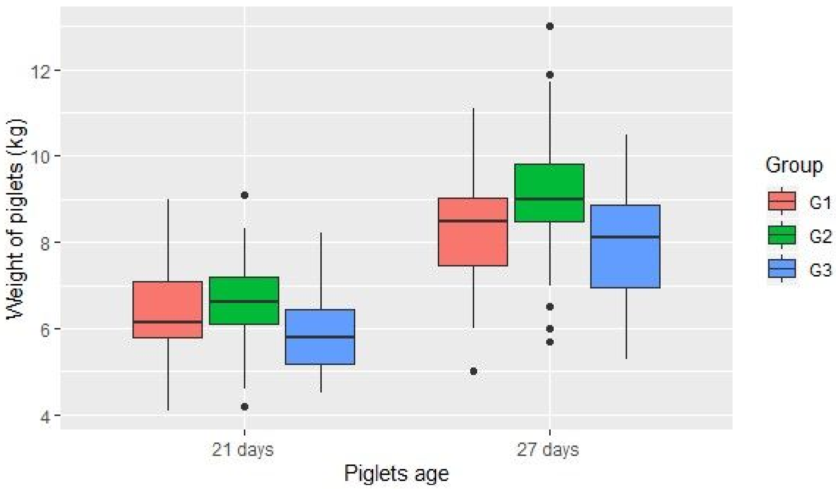

Figure 3

Boxplots to represent the weight of individual piglets at 21 and 27 days of age divided in three groups, according to sow lameness score (G1: lameness score 0-1; G2: lameness score 2-3; G3: lameness score 4-5). This figure was performed in the programming language R using the package ggplot2 52.

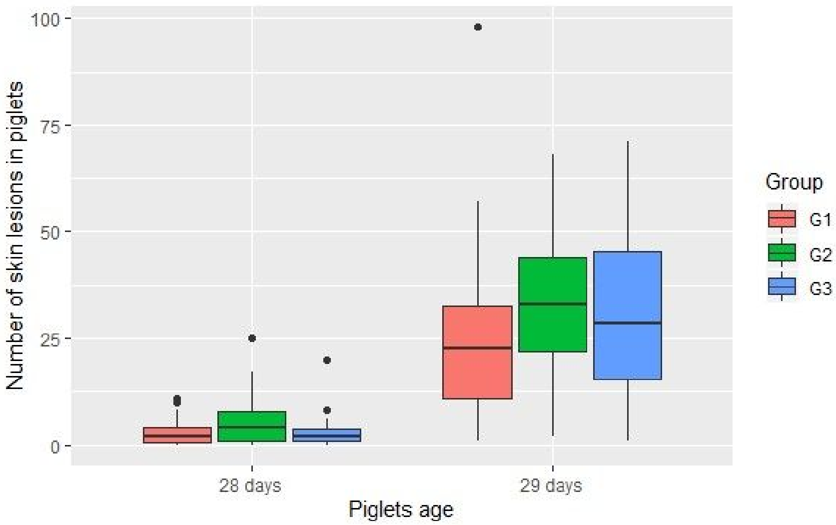

Figure 4

Number of skin lesions in piglets with 28 and 29 days of age, divided in three groups, according to sow lameness score (G1: lameness score 0-1; G2: lameness score 2-3; G3: lameness score 4-5). This figure was performed in the programming language R using the package ggplot2 52.

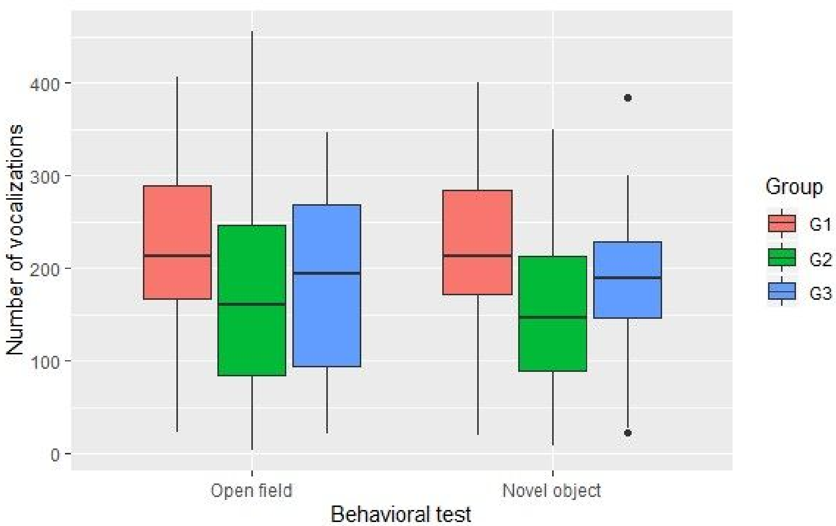

Figure 5

Number of piglet vocalizations during the open field and novel object test, divided in three groups, according to sow lameness score (G1: lameness score 0-1; G2: lameness score 2-3; G3: lameness score 4-5). This figure was performed in the programming language R using the package ggplot2 52.

Supplementary Files

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