Sound feeding signal for gestating sows: Evaluation of an individual learning strategy and its beneficial effects in groups

Anna Blanc, Clémentine Deroiné, Caroline Clouard, Charlotte Gaillard

Applied Animal Behaviour Science 275 (2024) 106302

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Sound feeding signal for gestating sows: Evaluation of an individual learning strategy and its beneficial effects in groups.

Anna Blanc, Clémentine Deroiné, Caroline Clouard, Charlotte Gaillard *

PEGASE, INRAE, Institut Agro, Saint-Gilles 35590, France

ARTICLE INFO

Keywords:
Feeding behavior
Aggression
Hierarchy
Conditioning
Sound discrimination
Welfare

ABSTRACT

Competition for feed in a group of gestating sows leads to aggression around feeding stations, which has a negative impact on their welfare. This study investigates the potential of teaching gestating sows an individual sound signal to reduce aggression resulting from competition for feed access, and thus improve their welfare in a group. A total of 32 sows were used. In a test room, “learning” sows ($n = 16$) went through 4 individual learning phases (27 days in total) to associate the individual sound signal with an invitation to feed from a one-way feeding station and to discriminate this individual sound signal from other unknown sound signals. After the learning phases, sows were subjected to a 3-day evaluation phase in groups of 4 sows. The "naive" sows ($n = 16$) were also introduced to the test room individually for 18 days, and in groups of 4 for 3 days without following the learning procedure. Learning sows correctly responded to 100% of their individual sound signal after only 8 days of individual learning, suggesting that they successfully associated the sound signal with feed access. Distinguishing between different sounds was harder as shown by only 18.8% of success after an unknown sound emission at the end of the individual learning phases. Naïve sows reduced the time spent in the feeder compared to learning sows ($P < 0.001$). On the second day of the group phase, learning sows were less aggressive than naïve sows ($P < 0.05$). Compared to high-ranking sows, low-ranking sows displayed a reduced number of spontaneous approaches to the feeder during the last individual learning phase ($P < 0.001$), and higher success rates in the group phase ($P < 0.05$). The study suggests that, for group-housed sows fed by an individual feeder, teaching sows an individual sound signal can modify their feeding and social behaviors, enhancing their overall well-being during feeding time. Furthermore, the results suggest that this individual learning may be particularly beneficial for low-ranking sows.

1. Introduction

The concept of welfare has become a major public concern, leading to a reconsideration of the practices and living conditions of farm animals (Rioja-Lang et al., 2020). Animal welfare is now defined at the individual level and is highly dependent on both the animal’s mental state and the quality of their captive environment. The animal must be able to find, in its environment, adequate housing conditions to meet its ethological needs such as access to feed, shelter and social interactions. Impoverished and monotonous housing conditions can lead to under-stimulation of the animals’ senses and cognition (Zebunke et al., 2013). The introduction of environmental enrichment such as bedding, substrates or objects encourages the animals to express species-specific behaviors, which has a positive effect on their well-being (Van De Weerd and Ison., 2019). Environmental enrichment can also consist in cognitive enrichment, that is giving the animals a degree of control over their environment, as well as providing engagement and feedback to the animal to allow for learning. This control can be expressed through the achievement of successful cognitive challenges that bring them satisfaction (e.g. feed reward; Milgram, 2003) and stimulate positive emotions.

Nowadays, the use of machines to automatize tasks and save time, such as feeding stations, is increasingly developing in farms to individualize animal monitoring (Garrido-Izard et al., 2022). A feeding station can be one-way (where entry is the same as exit) or two-way (where entry is different from exit) and animals have access to it one at a time. In group housing systems (e.g. fattening pigs and gestating sows), it ensures that each animal receives a complete feed ration every day. However, these machines can have a negative influence on the welfare of social farm animals as their access is typically regulated by the social

* Corresponding author.
E-mail address: charlotte.gaillard@inrae.fr (C. Gaillard).

https://doi.org/10.1016/j.applanim.2024.106302
Received 23 January 2024; Received in revised form 21 May 2024; Accepted 28 May 2024
Available online 29 May 2024

hierarchy within the group. Indeed, sows' access to feed and the order in which they enter the feeding station depend on their hierarchical status. The higher a sow ranks within the hierarchy, the quicker she has access to the feeding station (Durand et al., 2021). In these social groups, access to the feeder is regulated by agonistic behaviors, and up to 69% of all agonistic interactions can take place around the feeding station in groups of gestating sows, which has a negative impact on their welfare (Norring et al., 2019). Particularly, sows from low hierarchical rank are at a disadvantage, as they receive more aggression and have more difficulty accessing the feeding station (Bench et al., 2013). Furthermore, an increase in agonistic interactions between sows results in higher nutritional requirements for gestating sows due to increased physical activity (Gaillard et al., 2021; Durand et al., 2021). Therefore, current research in pig farming is focusing on developing new strategies to limit the competition around feeders for gestating sows.

To this end, some authors have shown that a form of cognitive learning, namely rewarded instrumental learning, could serve as a cognitive enrichment to reduce the negative effects inherent in the use of feeding stations. This method consists in rewarding animals with feed after they successfully discriminated an individual acoustic signal (Manteuffel et al., 2010; Kirchner et al., 2012, 2014). Research has shown that this method improves animal access to feeding stations, thereby reducing feeding competition and agonistic interactions (Manteuffel et al., 2009; Kirchner et al., 2012; Sonoda et al., 2013). In addition, this strategy can effectively reduce boredom (Ernst et al., 2005) and stress around feeding periods, and induce a positive anticipation of food intake (Manteuffel et al., 2010; Zebunke et al., 2011; Mahnhardt et al., 2014). The success of this method depends on the ability of pigs to associate a sound as an invitation to enter the feeder, but also on their capacity to discriminate their individual sound from the sounds of the other individuals of the group (Manteuffel et al., 2010). If these two conditions are fulfilled, each individual will be able to inhibit its presentation to the feeder in any situation that does not involve its individual sound.

Rewarded instrumental learning has been tested on pigs, sows and piglets via protocols in which animals learned to identify their signal directly in small groups, using two-way feeding stations (Manteuffel et al., 2009, 2010; Kirchner et al., 2012; Kirchner et al., 2014). In practice, however, farms can also have one-way feeding stations in which animals have to exit the station among waiting animals, which can lead to an increase in agonistic interactions.

Therefore, the objectives of the study were: (i) to determine whether gestating sows could learn, over four distinct and individual learning phases, to reach the feeder only when an individual acoustic signal is emitted; (ii) to assess whether the use of individual acoustic signals could reduce agonistic interactions and activity in front of a one-way feeding station in a group testing phase; and (iii) to determine the effect of the sow's hierarchical status on their individual learning performance.

2. Materials and methods

The experiment was carried out from February to June 2023 at the Pig Physiology and Phenotyping Experimental facility (https://doi.org/10.15454/1.5573932732039927E12) of the French National Research Institute for Agriculture, Food and Environment located in Saint-Gilles (France).

2.1. Animals and housing

2.1.1. Animals

Two batches of 16 gestating Landrace x Large White sows of mixed parities (ranging from 1 to 9, with an average of 3.61) were used.

2.1.2. Gestation room

Three days after their artificial insemination, each batch of sows entered a gestation room measuring 8.2 ×7.5 m. In each gestation room, the sows had access to feed through two automatic feeders (Gestal, JYGA Technologies Inc., Quebec, Canada). They consisted in a protective crate with a swing gate at the end that opens automatically when a sow presents herself and closes after she enters the device. The feeders were placed side by side perpendicularly to a wall, in the middle of the gestation room. Feeders were opened from 00:00 (e.g. feed cycle start) to 23:30, and the amount of feed administered to each sow throughout gestation depended on her parity and weight, and ranged from 2.4 kg to 3.3 kg per day. When they entered a feeder, sows were individually recognized with RFID (individual ear tag), and received 300-g portions of feed every 1 minute 30 seconds. There were neither entry restrictions nor time limitation in the feeder, allowing the sows to make several visits per day and stay as long as they wanted in the feeder, even once they had consumed all their ration (non-feeding visits). In this study, 600 g of the daily ration delivered by the feeders was withheld on the experimental days to be distributed in the experimental room (described below). In each gestation room, the sows had ad libitum access to water through two drinkers (Asserva, Lamballe, France).

2.2. Experimental protocol

2.2.1. Treatments

The sows were introduced to the experimentation when they were three weeks into their pregnancy. In each batch, half of the sows were taken to the experimental room and subjected to a learning procedure (8 learning sows per group per batch), while the other half were also taken to the experimental room but not exposed to the learning procedure (8 naive sows per group per batch). The sows were allocated to the two treatments to ensure homogeneity in terms of body weight and parity.

2.2.2. Experimental room and calling feeding station

The learning procedure was conducted in an experimental room of 54 m^2. The room consisted of two distinct areas (Fig. 1): a 44-m^2 L-shaped experimental area accessible to the animals, and the 10-m^2 observer area accessible only to the experimenters. The experimental area consisted of five areas in total. First, four fictitious areas: a play area, in which two jute bags and two ropes were available as enrichment materials (Horback et al., 2016); a transition area; a feeder area containing the manual feeder and a drinking trough, and the feeder entrance area. Play and transition areas were designed to give sows the opportunity to get away from the feeder and engage in other activities such as exploring the environment and enrichments. The last area in the experimental room is the one-way feeder (called in the feeder). It was similar in length (2.07 m),width (0.71 m) and design (e.g. gate opening and barriers) to the feeders in the gestation rooms, although it was placed against a wall and not in the middle of the experimental room as in gestation rooms. This feeder was manually opened and closed by the experimenter via a lever accessible from the observer area. A part of the sows' daily ration was distributed manually into the trough, which could be closed by a trap door. A loudspeaker (JBL Flip Essential 2) was positioned above the feeder. A fixed camera (Hikvision) and a mobile camera (GoPro Hero +) were installed so that the entire experimental area could be recorded during the experiment. The sows had access to the entire experimental area during the procedure.

2.2.3. Sound signals

As in the procedure used by Manteuffel et al. (2010), each sow's sound signal consisted of a trisyllabic non-word, to prevent any confusion with common words. Sixteen non-words such as 'mirlembar', 'vrapelu' and 'platinos' were generated in a way that no combination of three vowels was repeated. Sounds were recorded using a digital audio recorder (Olympus LS-P1) and spelled by a woman, as pigs show a preference for high-pitched voices (Tallet et al., 2020). Sounds were then standardized using Audacity 3.2.4. software to ensure that each sound signal lasted for 10 s, and that the non-word was pronounced

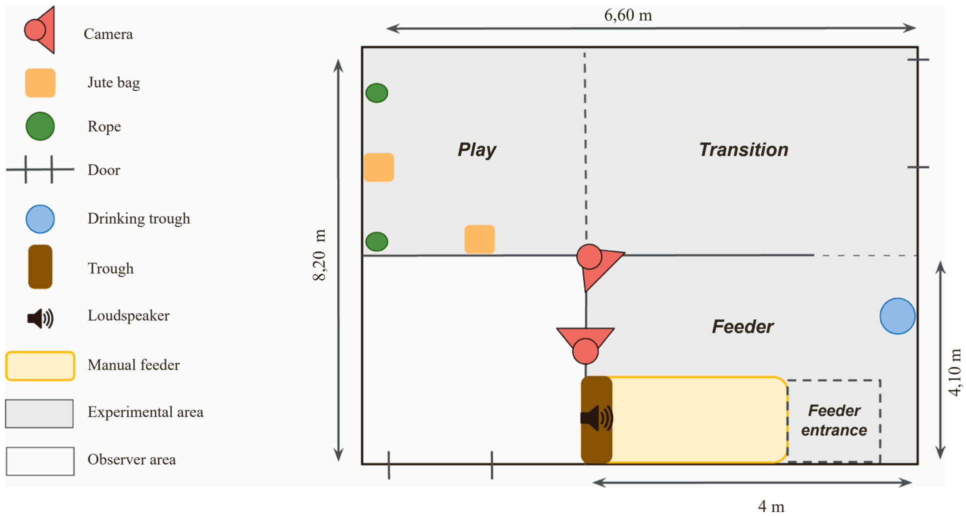

Fig. 1. Map of the experimental room.

three times at regular intervals during these 10 s. Each individual sound signal was assigned to a single learning sow, so that each sow had its own signal. Eight additional sound signals (called unknown sounds) were also created with the same characteristics as the individual sound signals but were not assigned to any animal. Also, a "repulsive" sound signal was created in case the sow did not leave the feeder after the feeding time set by the experimenters; it corresponded to a "beep" similar to the sound of a truck backing up repeated five times during 10 s. All the sounds were emitted at an intensity of 60 dB with the loudspeaker (JBL Flip Essential 2) positioned above the feeder.

2.3. Learning procedure

The learning procedure consisted of an adaptation phase followed by three distinct learning phases and a final testing phase. Animals were tested in the experimental room once or twice daily (depending on the phase), four to five testing days a week (no sessions during weekends) from 09:00 h to 12:00 h (AM sessions) or from 01:00 h to 05:00 h (PM sessions). Considering that the feed cycle starts at 00:00 h in the gestation room, all sows likely already had eaten their main daily feed ration before starting the procedure. They were tested individually for the first four phases (adaptation and learning phases) and in groups during the final testing phase. The order of passage during the day was determined randomly and changed daily, alternating between AM and PM sessions. During each testing day, the sows were allowed to visit the feeder twice per session, with 300 g of feed per visit. Sows had ad libitum access to water during the tests.

2.3.1. Adaptation phase

The phase of adaptation to the experimental room lasted two days with one session per day per sow, and was the same for both learning and naïve sows. The sow stayed in the room for 15 minutes and visited the feeder twice, with 300 g of feed available in the trough per visit. The experimenter opened the feeder when the two front legs of the sows crossed the feeder entrance area. When the sow entered the feeder, the experimenter closed the feeder and distributed the feed portion in the trough after opening the trap door. The sow was allowed to feed for 7 minutes per visit. After this time or after the trough was empty, the experimenter opened the feeder and the sow could voluntarily leave the feeder (step 0). If the sow did not leave the feeder voluntarily, the access to the trough was closed and the animal had one minute to exit the feeder (step 1). If the sow did not leave the feeder after 1 minute, the repulsive sound signal was emitted and, in the middle of the repulsive sound signal, the sow was encouraged to exit the feeder by lightly tapping its snout with a guide paddle (step 2). The aim was to associate this repulsive sound with the use of the guide paddle (e.g. positive punishment) to reduce the behaviour of standing in the feeder, and give them the opportunity to come out during the first five seconds of the repulsive sound. After the visit to the feeder, the sow was free to explore the experimental room and could enter a second time. After the two visits, the feeder door stayed closed even if the sow entered the feeder entrance area. During this phase, no sound signal was emitted except for the repulsive sound signal if necessary. At the end of the session, if the sow did not make at least one visit to the feeder, the quantity of feed not consumed during the session was added to the feed allowance in the feeders of the gestation pen for this same day. After this phase, maximum feeding time was reduced to 4 minutes, as it was observed that sows always finished eating between 1 minute 30 and 4 minutes.

2.3.2. Classical conditioning phase

The classical conditioning phase lasted 5 days, with one 15-min session per day per sow. Each sow was allowed to enter the feeder twice per session. As in the adaptation phase, access to the feeder was based on a voluntary approach by the animal. For learning sows, the individual sound signal was emitted as soon as the sow was in the feeder and had access to feed. No sound signal was emitted for naive sows, except for the repulsive sound signal if necessary. During each visit, the sow had access to a ration of 300 g and was allowed to feed for 4 minutes. After the visit to the feeder, the sow was free to explore the experimental room and could enter a second time. After the two visits, the feeder door stayed closed even if the sow entered the feeder entrance area.

2.3.3. Operant conditioning phase

The operant conditioning phase lasted 5 days, with one 15-minute session per day per sow. Each sow was allowed to enter the feeder twice per session. For the learning sows, first, the individual sound was emitted, and then, the sow had 1 minute to come to the feeder entrance area to trigger the opening of the feeder. The times at which the two individual sounds were emitted after the start of the session varied from day to day. As in the classical conditioning phase, the individual sound was emitted again when the sow was in the feeder and had access to feed to positively reinforce the classical conditioning previously established. If the sow failed to reach the feeder under the conditions described, the individual sound was emitted a third time at the end of the test and coupled with the distribution of feed in the trough to attract the animal to the feeder. For the naive sows, access to the feeder was similar to the classical conditioning phase and was based on a voluntary approach by the animal. No sound signal was emitted, except for the repulsive sound signal if necessary.

2.3.4. Discrimination phase

Initially, the discrimination phase lasted 4 days, with one 15-minute session per day per sow for both the learning and naïve sows. However, because learning sows required additional learning sessions to complete the task, they were subjected to 10.5 additional days, with two 15-minute sessions per day per sow, thus resulting in a total of 25 sessions over 14.5 days.

Each sow was allowed to enter the feeder twice per session. As in the classical conditioning phase, for learning sows, the sow's individual sound was emitted twice during the session and, each time, the sow had to enter the feeder entrance area to have access to the feeder. In addition to the emissions of the individual sound, two unknown sounds (same characteristics as the individual sound) were also emitted during the session. When these unknown sounds were emitted, the feeder door stayed closed even when the sow entered the feeder entrance area, to make sure sows learn that only their individual sound gives them access to feed. As a result, a total of four sounds were emitted in a random order, with a delay of 1 minute after the emission of the unknown sounds and 6 minutes after both emissions of the individual sound. This was done to ensure the sow had enough time to enter the feeder and to consume its ration after hearing the individual sound. As in the classical conditioning phase, once in the feeder, the individual sound of each learning sow was emitted again to positively reinforce the classical conditioning previously established. For naive sows, a total of 14 random sound signals were emitted per session, with one sound every minute, and access to the feeder was based on a voluntary approach. During each visit, the sow had access to a ration of 300 g and was allowed to feed for 4 minutes. After the visit to the feeder, the sow was free to explore the experimental room and could enter the feeder a second time. After the two visits, the feeder door stayed closed even if the sow entered the feeder entrance area.

2.3.5. Group phase

The group phase lasted 3 days, with one 90-minute session per day. During this phase, four groups of sows were tested: two groups consisting of four naive sows, and two groups consisting of four learning sows (groups remained unchanged throughout the phase). The sows were allocated to the groups to ensure homogeneity in terms of parity, body weight and hierarchical rank (described in part 2.4.1.) and were marked on the back with an animal marking crayon before everyday's session (RAIDEX) to ensure an individual identification by the observers. Furthermore, groups were constituted to ensure that each individual sound was unknown by the other three sows of the group. Each sow was allowed to enter the feeder twice per session. As in the discrimination phase, for learning sows, each sow's individual sound was emitted twice per session, and the sow had to enter the feeder entrance area to have access to the feeder. For the learning sows, a total of thirteen sounds were emitted at a 7-minute interval throughout the session, i.e. the individual sound for each of the four sows was emitted twice, and five additional unknown sounds were emitted once. The order in which the sound signals were emitted was semi-random, meaning that the first broadcast of each sow's individual sound occurred within the first period of the test ([0 min: 36 min]). For naïve sows, 13 sounds were also emitted at a 7-minute interval to ensure the same environmental condition as learning sows, and the feeder was accessed on the basis of a voluntary approach by the animal as in other phases. All sessions in this phase were video recorded.

2.4. Measures and observation methods

2.4.1. Determination of hierarchy

As hierarchy is strongly linked to the order in which gestating sows access the feeders in the gestation room (Lanthony et al., 2022), this feeder order was used to indirectly determine the hierarchical rank of the sows. The feeder order was determined by taking the first visit per feed cycle of every sow in the gestation room, from day 7 to day 13 after the sows' arrival to the gestation room (seven days in total). The sows were then classified into two hierarchical ranks: sows with a high hierarchy ranking (i.e. being among the first to visit the feeder every day, 8 naive and 8 learning sows) and sows with a low hierarchy ranking (i.e. being among the last to visit the feeder every day, 8 naive and 8 learning sows). If the sow's order to access feeder changed between days, a sow was considered among the high hierarchical ranking group if she was among the first eight sows to access the feeder at least five days out of the seven days observed, and conversely for sows with a low hierarchical rank.

2.4.2. Direct observations

The mean time spent in the feeder per test session (i.e. the mean of the two visits per session, in seconds) was measured in all learning phases and for all sows (learning and naïve).

For the learning sows in the operant conditioning, discrimination and group phases, the type of sound signal emitted (individual sound/unknown sound), the latency (in seconds) to arrive in the feeder entrance area after a sound emission and the sow's response (success *vs* failure) to the emission of the sound were recorded. The sow's response to a sound emission depended on the type of sound signal emitted (individual sound *vs* unknown sound) and the sow's approach to the feeder entrance area (yes *vs* no). There were two possibilities of success: the sow reached the feeder entrance area following the emission of its individual sound or it did not reach the feeder entrance area following the emission of an unknown sound. Conversely, there were two possibilities of failure: the sow did not reach the feeder entrance area following the emission of its individual sound and it reached the feeder entrance area following the emission of an unknown sound. Based on this measurement, a percentage of success was calculated.

For all sows in the discrimination and group phases, the number of spontaneous presentations to the feeder, defined as the number of times the animal entered the feeder entrance area and tried to get access to the feeder in the absence of sound, was counted. In this case, the feeder was not opened since the spontaneous presentation to the feeder is not a response to the individual sound.

For all sows in the group phase, the total number of scratches (superficial linear wound) and lesions (any wound, abrasion, or redness on the sow's body that is not a scratch) present on the entire body of the sows was counted before and after each session. The total number of injuries (scratches + lesions) before was subtracted from the number of injuries after to obtain the number of new injuries per session.

2.4.3. Video observations

Video observations were made on both learning and naive sows, during the 3 sessions of the group phase (last phase). The 90-minute videos recorded during the group phase were analyzed using a scan sampling method with an interval of two minutes between each scan, resulting in a total of 45 scans per session. For each scan, two categories of behaviors were scored for each sow individually: the location in the room (in the feeder, and in the feeder entrance, feeder, transition and play areas; Fig. 1), and the posture (sitting, standing, lying down; Table 1). The percentage of total scans per location and posture were calculated. The total number of agonistic behaviors (Table 1) expressed by the sows in the areas around the feeder (in the feeder, and in the feeder entrance and feeder areas) was also scored continuously on the 90-min video recordings using the all-occurrence behavioral sampling method (by counting agonistic events).

2.4.4. Salivary cortisol measurements

To measure the effect of the learning strategy on sows' chronic stress, salivary cortisol was measured on all sows before and after the learning procedure. Saliva samples were collected on all sows on the day

Table 1
Ethogram of postures and agonistic behaviors of the sows used to score behaviors in the group phase (adapted from Kirchner et al. 2012 for agonistic behaviors).

Posture	Description
Standing	The sow stands on all four legs. It may be motionless or moving.
Lying down	The sow's chest and hindquarters touches the ground. It may be lying laterally (4 legs visible, line of back not visible), ventrally (4 legs not visible, line of back visible), or ambiguously (neither laterally nor ventrally).
Sitting	The sow's chest is off the ground, the front legs are straight with at least one of the two hind legs bent under the body.
Behaviors	**Description**
Agonistic behavior	A sow is aggressing another sow. This category contains five types of aggression: bite, threat, pushing, chasing and fighting, described below. Bite: A sow makes a rapid head movement towards a congener, head stretched out and mouth open, and touches the congener with her open mouth once or several times. Threat: A sow makes a rapid head movement, possibly mouth opened, towards the congener, without direct contact between the two sows. Pushing: A sow uses her head to make contact with a conspecific and, with repeated movements, rubs the conspecific to move it. Chasing: A sow chases a conspecific, with both animals in motion. The chasing sow is behind the pursued sow, but there is no direct contact between sows. Fighting: Two sows make physical contact in an anti-parallel position, circling each other and pushing, threatening or biting each other.

preceding the start of the learning procedure (one day before the beginning of adaptation phase) and on the day following the end of the procedure (one day after the end of group phase). Saliva was systematically sampled in the gestation room between 09:00 h and 09:30 h by allowing the sows to chew on a cotton bud (Salivette®, Sarstedt 51588 Nümbrecht, Germany) until it was moistened. Cottons were then placed in 1.5-mL tubes directly after sampling and stored on ice until all samples were taken. Samples were centrifuged at 2500 G for 10 min at 4°C and stored at −20 °C until further analysis. Salivary cortisol concentrations (ng/mL) were measured using a luminescence immunoessays kit (LIA, IBL, Hamburg, Germany).

2.5. Statistical analysis

Data were analyzed phase by phase using R statistical software (R R Core Team, 2023). Normality of distribution was tested using Shapiro test and equality of variance was tested using Bartlett test. Discrete quantitative variables, including the percentage of total scans spent in different areas of the room and in different postures, the number of agonistic behaviors, injuries and spontaneous presentations to the feeder were analyzed using generalized linear mixed models (GLMM) based on the Poisson distribution, with the logarithmic function as the link function. The success variable (response), with a closed interval [0, 1], was analyzed using a generalized linear mixed model (GLMM) based on a binomial distribution (percentage of success) with a logit link function. Continuous quantitative variables, including time spent in the feeder and salivary cortisol concentrations, were analyzed using linear mixed-effects models (LMER) after normalizing the data using the log function. The latency of arrival at the feeder, being a continuous quantitative variable with an asymmetric distribution, was analyzed using a generalized linear mixed model (GLMM) based on the Gamma distribution and the logarithmic link function.

Analyses performed only on learning sows (response to sound, latency of arrival to the feeder entrance area) included day, hierarchical status (low or high) and sound type (individual or unknown) as fixed factors, and sow identity as a random factor. Analyses designed to compare naïve and learning sows (spontaneous and motivated presentations, agonistic behavior, location and posture scans) included treatment (naïve or learning), hierarchical status (low or high) and day as fixed factors, as well as sow identity as a random factor. In the group phase, the group was added as a random factor for the analyses.

The models were first run using the glmer and lmer functions from the lme4 package (Bates et al., 2015). If GLMMs were exposed to overdispersion, they were corrected using the glmmPQL function from the MASS package (Venables and Ripley, 2002). Main effects were calculated using the Anova method of the car package (Fox and Weisberg, 2019), and correlations between different fixed factors were calculated using the emmeans function (Lenth., 2023). Multiple comparisons between the same fixed factor (e.g. day-by-day comparison) were performed using the Tukey-Kramer procedure (Kramer, 1956). Figures were created using the ggplot2 package (Wickham, 2009). Data are presented as mean ± SEM.

3. Results

3.1. Evaluation of learning procedure on learning sows

3.1.1. Percentage of successful responses to sounds

3.1.1.1. Effect of day and type of sound. The effect of day on the percentage of successful responses of learning sows to sounds during the 3 learning phases is shown in Fig. 2. In the operant conditioning phase, there was no significant effect of day on the percentage of success ($P = 0.62$) which reached 100% by day 3. In the discrimination phase, the percentage of success was significantly affected by the day and the type of sound (interaction, $P = 0.04$). While the percentage of success for the individual sounds remained close to 100% for the whole phase, the percentage of success for the unknown sounds stayed around 0% during the 10 first days of this phase (d6 to 15), and compared to the first day of the phase (d6), tended to increase on the following 2 days (d6: 0.00% *vs* d16: 12.5 ± 4.1%, $P = 0.05$; d17: 9.4 ± 5.2%, $P = 0.06$), and was significantly increased on the 3 last days (d18: 17.2 ± 4.8%, $P = 0.01$; d19: 14.1 ± 4.4%, $P = 0.02$; d20 18.8 ± 4.9%, $P = 0.01$). Over the three days of the group phase, learning sows averaged 52.9 ± 3.1% success. They had a better percentage of success when the sound emitted was their individual sound than when it was an unknown sound (71.8 ± 4.2% *vs* 33.9 ± 2.1%, $P < 0.001$).

3.1.1.2. Effect of hierarchical rank and type of sound. The sows' hierarchical rank had no effect on the percentage of success in the operant conditioning phase ($P > 0.05$). In the discrimination phase, there was a significant effect of the hierarchical rank and the type of sound on percentage of successful responses (interaction, $P = 0.04$), with sows from a low hierarchical rank responding better to the unknown sounds than those from a high hierarchical rank (12.5 ± 1.7% *vs* 4.0 ± 0.9% success, $P = 0.02$). However, during this phase there was no effect of hierarchical status on percentage of success for individual sounds ($P = 0.61$). In group phase, the interaction between hierarchical rank and type of sound indicated that low-ranking sows responded better to unknown sound than high-ranking sows (45.2 ± 3.2% *vs* 22.9 ± 2.6% success, $P < 0.001$), but there was no effect of hierarchical rank when the individual sounds were emitted (63.0 ± 48.7% *vs* 81.8 ± 38.9% success, $P = 0.67$).

3.1.2. Latency of arrival to the feeder

3.1.2.1. Effect of day and type of sound. In the operant conditioning phase, the average latency of arrival to the feeder entrance area after a sound was emitted was 10.9 ± 1.2 sec, and was not affected by day ($P = 0.20$, Fig. 3). In the discrimination phase, day and type of sound had a significant effect on the latency of arrival to the feeder (interaction, $P < 0.001$, Fig. 3). From day 8 onwards, the latency to arrive in the feeder entrance area when an individual sound was emitted became

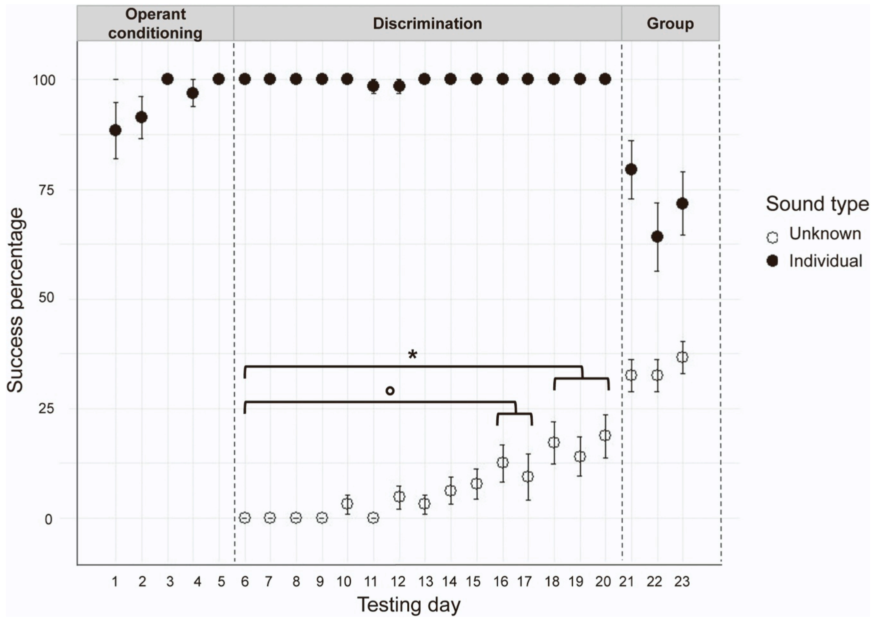

Fig. 2. Effect of testing day and sound type (individual *vs* unknown) on the percentage of successful responses of learning sows during the operant conditioning, discrimination and group phases. For each testing day, the symbol indicates a significant difference in the percentage of success compared to day 6 for the unknown sound (° $0.05 \leq P < 0.1$; * $P < 0.05$).

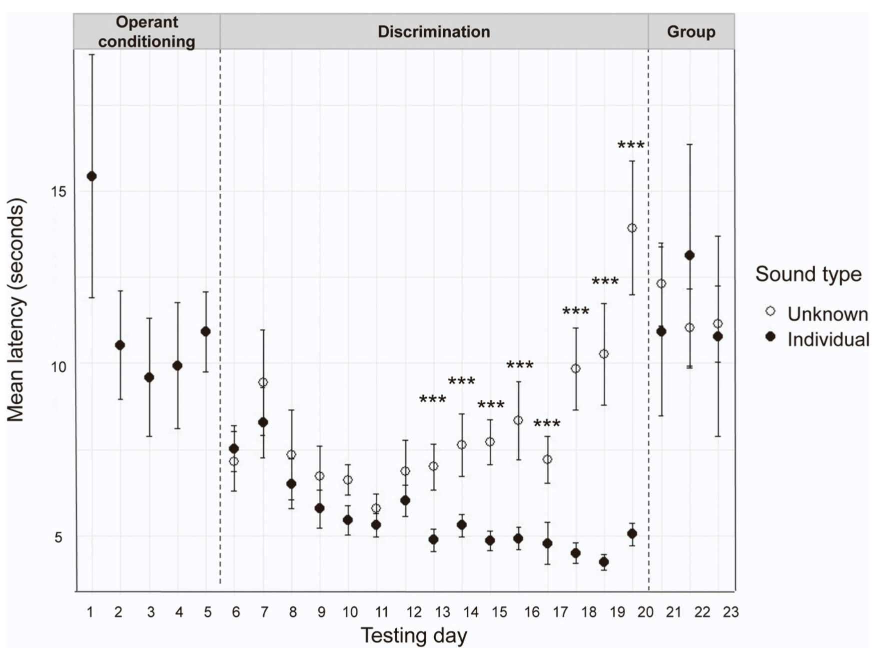

Fig. 3. Effect of testing day and sound type (individual *vs* unknown) on the latency to reach the feeder entrance area during the operant conditioning, discrimination and group phases. For each testing day, the symbol indicates a significant difference in the latency to reach the feeder entrance area between the individual and unknown sounds (***$P < 0.001$).

significantly lower than when an unknown sound was emitted, and remained so until the end of this phase ($P < 0.001$ for each day). In the group phase, there was no effect of day ($P = 0.20$) or type of sound ($P = 0.28$) on the latency to reach the feeder entrance area.

3.1.2.2. Effect of hierarchical rank and type of sound. Hierarchical rank and type of sound had no impact on the latency to reach the feeder entrance during the operant conditioning and discrimination phases. However, in the group phase, latency to access the feeder entrance area was affected by hierarchical rank and the type of sound (interaction, $P = 0.006$), with only low-ranking sows having a lower latency when their individual sound was emitted compared to an unknown sound (9.7 ± 2.1 sec *vs* 12.1 ± 1.1 sec, $P = 0.01$).

3.2. Behavioral changes in learning sows compared to naïve sows

3.2.1. Time spent in the feeder

3.2.1.1. Effect of day and treatment. In the classical conditioning phase, day and treatment (leaning *vs* naïve) had an effect on the time spent in the feeder (interaction, P = 0.01). On the first 4 days, the time spent in the feeder did not differ according to the treatment, whereas, on the last day, naïve sows spent less time in the feeder than learning sows (169.2 ± 9.1 sec *vs* 200.8 ± 10.7 sec, P = 0.04). In the operant conditioning and discrimination phases, naïve sows spent less time eating in the feeder than learning sows (operant conditioning phase: 145.7 ± 2.9 sec *vs* 219.3 ± 4.7 sec; discrimination phase: 134.3 ± 3.7 sec *vs* 236.4 ± 1.5 sec, P < 0.001 for both) and this difference increased over days (P < 0.001 for both phases, Table 2).

In contrast to the other phases, time spent in the feeder was not influenced by the treatment in the group phase (P > 0.75; Table 2). However, there was a significant effect of day (P < 0.001), with sows spending less time in the feeder on day 1 than on days 2 and 3 regardless of the treatment (d1: 195.9 ± 13.7 sec *vs* d2: 274.0 ± 12.1 sec, P = 0.05; d3: 268.8 ± 9.0, P= 0.01).

3.2.1.2. Effect of hierarchical rank and treatment. The sows' hierarchical rank had no impact on the time spent in the feeder during the classical conditioning, operant conditioning and discrimination phases, regardless of the treatment (Table 2). However, in the group phase, there was a significant effect of the treatment and hierarchical rank (Table 2). Naive sows from a low hierarchical rank spent more time in the feeder than naïve sows from a high hierarchical rank (P < 0.001). Conversely, learning sows from low hierarchical rank spent less time in the feeder than learning sows from high hierarchical rank (P < 0.001).

3.2.2. Number of spontaneous presentations to the feeder

3.2.2.1. Effect of day and treatment. As learning sows completed more test days than naive sows in the discrimination phase (14.5 *vs* 4 days), statistical analyses were done, first, on the 4 days in which both learning and naïve sows were included, and then, on the following 10.5 days in which only learning sows were included.

During the first 4 days of the discrimination phase, learning sows spontaneously presented themselves more at the feeder than naive sows (6.8 ± 0.3 *vs* 5.9 ± 0.4 presentations, P < 0.001). All sows spontaneously presented themselves more on the first day than on the three following days (d1: 9.7 ± 1.2 *vs* d2: 6.2 ± 0.7; d3: 7.7 ± 0.7; d4: 7.9 ± 1.1, P = 0.01 for all). For the rest of the discrimination phase (10.5 days), the number of spontaneous presentations at the feeder by learning sows decreased over days (P < 0.001). In the group phase, the number of spontaneous presentations at the feeder decreased over days regardless on the treatment (d1: 21.8 ± 1.9 *vs* d2: 20.7 ± 2.3; d3: 16.6 ± 1.7, P < 0.001 for all).

3.2.2.2. Effect of hierarchical rank and treatment. In the discrimination phase, sows with low hierarchical rank spontaneously presented themselves at the feeder when no sound was emitted less than sows with high hierarchical rank (5.7 ± 0.3 *vs* 7.8 ± 0.4, P < 0.001), regardless of the treatment. In the group phase, this difference was no longer significant (P = 0.18).

3.3. Evaluating the benefits of learning during the group phase

3.3.1. Agonistic behavior

3.3.1.1. Effect of day and treatment. There was an interaction between day and treatment (P = 0.02), with learning sows being less aggressive than naïve sows, but only on day 2 (P = 0.02; Fig. 4). Furthermore, all sows were more aggressive on the first day compared with days 2 and 3 (d1: 19.9 ± 2.6; d2: 9.7 ± 1.4; d3: 8.56 ± 1.3, P < 0.001 for both, Fig. 4).

3.3.1.2. Effect of hierarchical rank and treatment. Sows from low hierarchical rank were less aggressive than sows from high hierarchical rank regardless of the treatment (11.1 ± 1.2 *vs* 14.5 ± 1.9, P < 0.001).

3.3.2. Number of injuries

Day and treatment had no effect on the total number of injuries, scratches and lesions (P > 0.1 for all, Table 3). The hierarchical status did not affect the total number of injuries (P = 0.15) or lesions (P = 0.82), but had an effect on the number of scratches, with sows with low hierarchical rank having more scratches than sows with high hierarchical rank (P = 0.03).

3.3.3. Location and posture

Overall, sows spent more time in the feeder area than in other areas (feeder area: 38.7 ± 6.7%, feeder entrance area: 12.7 ± 2.6%, transition area: 11.3 ± 3.2%, play area: 19.2 ± 4.7%, in the feeder: 7.23 ± 1.4%, P < 0.001), but tended to spend less time in the feeder area over days in the group phase (d1: 41.4 ± 5.5%, d2: 37.6 ± 6.4%, d3: 37.0 ± 7.3%, P = 0.08).

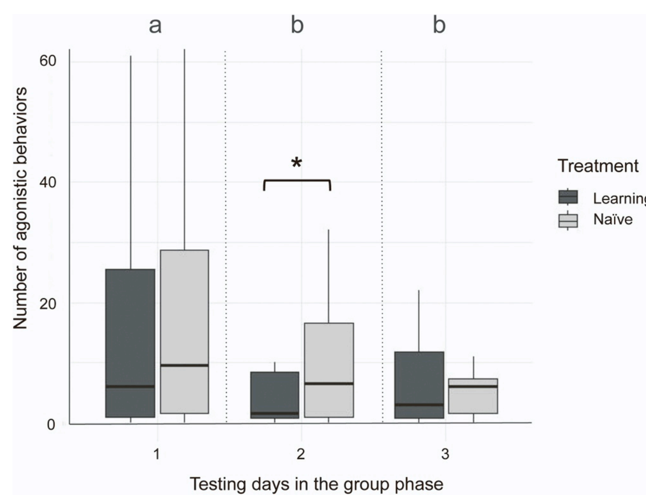

Fig. 4. Effect of testing day and treatment (learning *vs* naïve sows) on the average number of agonistic behaviors per session during the group phase. The asterisk indicates a significant treatment effect on testing day 2 (*P < 0.05). Two different letters indicate significant difference between testing days (P < 0.001).

Table 2
Effect of treatment (learning *vs* naïve), hierarchical rank (low *vs* high) and their interaction on the mean time spent in the feeder (seconds) during the individual learning phases and the group evaluation phase. N.S. non-significant; *P < 0.05; **P < 0.01; ***P < 0.001.

	Learning		Naïve		P values		
	Low	High	Low	High	Treatment	Hierarchical rank	Interaction
Classical conditioning	227 ± 5.69	230 ± 6.09	200 ± 4.69	205 ± 5.84	N.S.	N.S.	N.S.
Operant conditioning	229 ± 6.48	210 ± 6.58	149 ± 3.44	142 ± 4.79	***	N.S.	N.S.
Discrimination	237 ± 2.22	235 ± 2.15	138 ± 6.16	131 ± 4.38	***	N.S.	N.S.
Group	211 ± 23.8	297 ± 9.18	244 ± 12.1	213 ± 13.6	N.S.	**	***

Table 3
Effect of treatment (learning *vs* naïve) and hierarchical status (low *vs* high) during the group phase on the mean number of injuries (scratches, lesions and total) per individual per testing day, the mean percentage of time spent in different locations and postures per individual per testing day, and the mean cortisol concentrations (ng/mL) taken one day before and one day after the learning procedure per individual. N.S. non-significant; *P < 0.05; **P < 0.01; ***P < 0.001.

		Learning		Naïve		P values		
		Low	High	Low	High	Treatment	Hierarchical status	Interaction
Mean number of injuries per testing day	Scratches	3.75 ± 0.70	2.42 ± 0.57	3.08 ± 0.77	1.54 ± 0.59	N.S.	*	N.S.
	Lesions	1.33 ± 0.48	1.79 ± 0.74	1.63 ± 0.51	1.42 ± 0.55	N.S.	N.S.	N.S.
	Total	5.08 ± 0.83	4.21 ± 0.97	4.71 ± 0.94	2.96 ± 0.88	N.S.	N.S.	N.S.
Mean percentage of time spent in each location per testing day	In the feeder	4.17 ± 1.01	10.4 ± 1.05	8.88 ± 1.88	7.88 ± 1.52	N.S.	***	***
	Feeder entrance area	13.8 ± 3.25	14.4 ± 1.90	13.1 ± 1.99	16.0 ± 3.05	N.S.	N.S.	N.S.
	Feeder area	45.6 ± 5.47	46.6 ± 6.15	36.8 ± 5.04	45.2 ± 6.52	N.S.	N.S.	N.S.
	Transition area	14.7 ± 3.39	9.33 ± 2.28	13.9 ± 3.51	11.9 ± 3.05	N.S.	N.S.	N.S.
	Play area	21.1 ± 5.24	19.0 ± 4.69	27.3 ± 5.10	19.0 ± 3.62	N.S.	N.S.	N.S.
Mean percentage of time spent in each posture per testing day	Standing	91.4 ± 7.79	95.3 ± 4.90	95.5 ± 2.97	81.7 ± 6.18	N.S.	N.S.	N.S.
	Lying	7.25± 8.11	3.89 ± 4.48	4.44 ± 2.88	17.4 ± 5.34	N.S.	N.S.	N.S.
	Sitting	0.63 ± 0.89	0.63 ± 0.54	0.09 ± 0.20	0.91 ± 1.08	N.S.	N.S.	N.S.
Salivary cortisol, ng/mL	Before	1.45 ± 0.29	1.38 ± 0.40	1.82 ± 0.75	1.77 ± 0.49	N.S.	N.S.	N.S.
	After	1.54 ± 0.30	1.66 ± 0.22	1.24 ± 0.25	1.61 ± 0.36	N.S.	N.S.	N.S.

The percentage of scans spent in the feeder was significantly affected by treatment and hierarchical rank (interaction, P < 0.001; Table 3). Low–ranking learning sows spent fewer scans in the feeder than high–ranking learning sows, whereas there was no difference between hierarchical rank for naive sows (P = 0.42).

Sows spent more time standing than in other postures (standing: 91.0 ± 9.0%, sitting: 0.57 ± 0.8%, lying: 8.24 ± 8.8%, P < 0.001), but they tended to spend less time standing over days (d1: 94.7 ± 7.3%, d2: 90.5 ± 8.9%, d3: 87.8 ± 10.5%, P < 0.001). The treatment or hierarchical status had no impact on their posture (P = 0.24 and P = 0.87, respectively, Table 3).

3.3.4. *Cortisol concentrations*

Cortisol measurements were not significantly different before or after the learning procedure (P = 0.49), and there was no effect of treatment or hierarchical rank on the concentration of cortisol before or after the learning procedure (P = 0.81 and P = 0.77, respectively; Table 3).

4. Discussion

The aim of this study was to evaluate the effectiveness of a call feeding based on an individual learning strategy in reducing agonistic interactions at the feeder within groups of gestating sows and in limiting the effect of hierarchy by giving subordinate sows better access to feed. Sows subjected to the learning procedure rapidly reached high success rates after the emission of a known individual sound, but success rates remained low throughout the procedure after the emission of unknown sounds. The learning procedure increased time spent in the feeder during the individual learning phases, and decreased agonistic behaviors on the second day of the group testing phase.

4.1. *Sow's ability to associate a sound with the distribution of feed*

The association between a sound and the opening of the feeder was rapidly achieved, with the learning sows having an overall success rate following the emission of the individual sound of 90% in the operant conditioning phase, and this rate remaining high throughout the following individual phases. These results suggest that the association between a sound emission and access to the feeder is effective in gestating sows, and support prior findings in sows and pigs (Manteuffel et al., 2010; Puppe et al., 2007).

Although sows seemed capable of associating the emission of a sound with the distribution of feed, they struggled to discriminate unknown sounds from individual sounds, as shown by a low success rate after the emission of unknown sounds in the discrimination phase. Over days, however, the percentage of successful responses after the emission of an unknown sound increased (from 0% on the first day to 18.8% on the 15th day of this phase), suggesting that the sows started to discriminate their own sounds from unknown sounds, but might have needed more time to fully learn to discriminate the sounds. This hypothesis is supported by the increase over days in the latency to present at the feeder following the emission of an unknown sound during the discrimination phase. Remarkably, from day 8 onwards, this latency even became higher than the latency observed after the emission of their individual sound. These results suggest that, even if the sows presented themselves at the feeder after the emission of an unknown sound (i.e. wrong response), they were likely capable of differentiating the different sounds. Similar results have been observed in a previous study, showing a decrease in approaches after an unknown sound, reaching less than 5% of approaches to unknown sounds on the total number of unknown sounds emitted on the last day of a 13-day operant conditioning phase (Manteuffel et al., 2010). The presence of the group during training in their study may have accelerated the sound discrimination process, as presentation to the feeder at an unknown sound was not only unrewarded by feed, but also negatively reinforced by potential agonistic interactions.

In the domestic pig, vocal communication is highly developed, and the acoustic characteristics of vocalizations differ according to the context in which they are produced, demonstrating the pigs' fine ability to discriminate between different sounds (Tallet et al., 2013). For example, according to Illmann et al. (2002), sows may be able to discriminate familiar sounds in a known context from unfamiliar or incongruous sounds. Therefore, it is highly likely that the sows in our study were able to discriminate between sound signals.

4.2. Conflicting effects of sows' learning abilities and motivation to feed

Despite their apparent ability to discriminate sounds, many sows in our study presented themselves to the feeder even after the emission of an unknown sound. Furthermore, the number of spontaneous presentations to the feeder was higher among learning sows compared to naïve sows, which indicates that they attempted to force entry to the feeder. While naïve sows could access the feeder at any time from the beginning of the session by spontaneously presenting themselves in front of the feeder, learning sows often had to wait several minutes before the emission of their specific sound. The motivation to eat therefore remained consistently higher in learning sows compared to naïve sows during the learning process, as they are still searching for feed (Lawrence et al., 1988). Furthermore, in the sows' gestation pen, the feeder is designed to automatically open when a sow comes in front of it. As a result, the strategy employed by sows is to stay close to the feeder and attempt to enter it as soon as it becomes available. The procedure tested in our study forces sows to learn a new feeding strategy that requires them to wait for their individual sound, which could lead to increased levels of frustration, and thus result in a higher number of spontaneous presentations and responses to unknown sounds. A study testing a similar learning strategy on cows suggested that the animals could take longer to understand that the absence of a sound consistently means the absence of feed (Wredle et al., 2004). A decrease in the number of spontaneous presentations over time in the discrimination phase suggests that sows began to understand that the strategy of presenting spontaneously at the feeder was no longer effective in this context. In the group phase, we also observed a decrease in spontaneous presentations over testing days, as well as a decrease in time spent in the feeding area and time spent standing. However, there was no difference in activity (location and posture) between learning and naïve sows. Extending the group phase would be interesting to observe the long-term effects of the learning strategy on their activity around the feeding station, as three days seems too short to draw conclusions. Our hypothesis is that, in the long term, they may be able to abandon the old feeding strategy in favor of the new strategy brought by the learning procedure. This could lead to a reduction of sows' activity around the feeder, and therefore an easier access to the feeding station for all individuals. This effect would be particularly interesting in systems with one-way feeders such as in this experimental station, as it would allow the sow in the feeder to move back more easily, without being disturbed by other individuals. Further studies could also consider introducing a "negative" sound signal associated with a punishment, such as an air blast, whenever the sow approaches the feeder when an unknown sound is emitted (Wredle et al., 2004). This strategy could help deter the queuing behaviour, as well as speeding up the learning process.

4.3. Comparison between different learning strategies

In line with prior research in gestating sows (Manteuffel et al., 2010) and growing pigs (Puppe et al. (2007), we reported that gestating sows are able to learn to associate an individual sound to access to feed. However, while in our study success rates already reached 80% on the very first day of the operant conditioning phase, prior studies reported significantly longer learning durations. In the study of Manteuffel et al. (2010), sows were called six times per day for two weeks, and needed about 50 individual calls to reach a 80-% success rate to their individual sound. Similarly, in the study of Ernst et al. (2005), pigs needed about seven days of operant conditioning, with 24 sounds per day per pig, resulting in a total of 100 individual calls, to reach a 80-% success rate. These longer learning durations can be attributed to differences in experimental protocols and to a greater complexity of the procedures. In the aforementioned studies, the entire learning procedure was performed in groups (6 gestating sows, Manteuffel et al., 2010; 8 growing pigs, Ernst et al., 2005). Therefore, both individual and unknown sounds were emitted from the operant conditioning phase onwards, and animals had to simultaneously learn to identify their individual sound as a call to feed and to discriminate their individual sound from other unknown sounds. Furthermore, in the study of Ernst et al. (2005), pigs had simultaneous access to 4 automatic feeders delivering a sound signal specific to each pig of the group, which significantly increased the complexity of the task as the pigs had to identify which feeder was emitting the sound. Overall, the modality of learning (individual *vs* collective), the number of individuals in the groups and the number of call feeding stations in the pen can influence the efficiency of the learning procedure.

4.4. Effect of the learning strategy on sows' welfare

The number of agonistic behaviors was high for all sows on the first day of the group phase, which is typical of the establishment of hierarchy between animals (Verdon et al., 2015). Although the sows, which originated from the same group, already knew each other, their redistribution into subgroups of four sows led to the establishment of a new hierarchical order, and therefore to an increase in aggression between individuals (Zurbrigg and Blackwell, 2006). However, we observed a greater reduction in these agonistic behaviors on the second day of the group testing phase for learning sows compared to naive sows, indicating that the call feeding strategy was successful in reducing aggression (Kirchner et al., 2012; Sonoda et al., 2013). The number of injuries, however, did not differ between learning and naïve sows. This result could suggest that the learning strategy did not reduce harmful agonistic behaviors, such as bites, but only agonistic behaviors which do not lead to injuries, such as threats and pushes. Further studies including a detailed analysis of agonistic behaviors should help understanding how this learning strategy affects aggression between sows. Alternatively, the absence of noticeable effect of the call feeding on body injuries may be attributed to the low incidence of injuries at the start of the group phase, thereby limiting opportunities for observable improvement. This initial low incidence of injuries may reflect low levels of aggression, which may be linked to the small size of the groups in our study. Notably, the presence of only four individuals simultaneously in the experimental room reduced the chances of sows being aggressed by other sows compared to the gestating room, where sows were housed in larger groups of approximately 18 individuals. Conversely, larger group sizes often induce a strong effect of hierarchy, thus increasing the occurrence of injuries during the learning procedure, as shown by Manteuffel et al. (2022).

In our study, we found no differences of salivary cortisol concentrations at the end of the learning procedure between learning and naïve sows, suggesting that the learning strategy had no significant impact on the level of stress in our groups of gestating sows. In growing piglets, announcing feeding times via a sound cue increased heart rate when the feeding times were random, but not when the feeding times were fixed, suggesting that piglets were stressed when the sound order was randomized (Mahnhardt et al., 2014). This difference can be explained by the fact that piglets may be more impacted by the inability to anticipate feeding time as they are more sensitive to stress than experienced sows. We can assume that, if there is a positive effect of a fixed sound order in piglets, it may also be beneficial for sows. Thus, coupling the call feeding strategy with a fixed feeding schedule, and thus enabling sows to anticipate their feeding time, could be aneffective method to further reduce feeding-related stress responses and improve welfare of group-housed gestating sows. This hypothesis should be tested by implementing call feeding stations directly in the gestation room, as the final purpose is to validate whether this learning strategy can be used in the gestation room to improve welfare and reduce stress of group-housed sows.

In the operant conditioning and discrimination phases, naïve sows spent less time in the feeder over days, while learning sows remained consistent in their time spent in the feeder. However, during the group phase, the time spent in the feeder was no longer different between naïve and learning sows, suggesting that naïve sows reduced their time spent in the feeder only when they were alone in the experimental room. It is worth noting that the time spent in the feeder did not necessarily reflect the time taken to eat their full ration. During the experiment, we observed that naïve sows quickly exited the feeder after finishing their ration, whereas learning sows waited longer in the feeder after finishing their ration. We posit that, since access to the feeder was easier for naïve sows, they were habituated to entering and leaving the feeder effortlessly. Consequently, they quickly exited the feeder to present themselves again and receive a new ration. On the other hand, access to the feeder for learning sows posed a greater challenge, as they had to wait for their individual sound cue for access. Thus, learning sows may have chosen to remain in the feeder longer, uncertain of when their next opportunity to access it would occur. Further studies should consider measuring the time taken by sows to eat their ration, as well as the overall time spent in the feeder to better understand the impact of learning strategy on time spent in the feeder.

4.5. An individual learning strategy beneficial primarily for low-ranking sows

During the operant conditioning and discrimination phases, high- and low-ranking sows generally had the same success rates. This result contrasts with prior research in which low-ranking sows trained in groups of 8 sows followed fewer calls and needed more calls to reach the learning criterion than high-ranking sows (Manteuffel et al., 2010). While we used an individual learning approach, Manteuffel et al. (2010) used a group-based learning approach. In these conditions, high-ranking animals tend to block the space near the feeding station (Hunter et al., 1989), by consistently staying close to the feeder, thus leaving limited opportunities for the low-ranking sows to respond to their calls, as they feared approaching the feeder.

In contrast, our results suggest that sows of lower hierarchical rank may have somehow learned better, as shown by a higher percentage of success during the discrimination phase, a higher latency to arrive at the feeder after the emission of an unknown sound, and a lower number of spontaneous presentations compared to high-ranking sows. These results suggest that low–ranking sows learned and integrated the new feeding strategy of waiting for their own sound more easily than high-ranking sows, whereas high-ranking sows kept attempting to open the feeder by force even when their own sound was not emitted. High-ranking sows are more likely to be the oldest sows (Lanthony et al., 2022). Therefore, sows from higher hierarchical rank may have had more difficulty adapting to the new feeding strategy because they had been exposed to the conventional feeder and had been using the strategy of waiting in front of the feeder for an extended period of time compared to young sows (Manteuffel et al., 2022).

In the group phase, low-ranking sows also had a better success rate. As mentioned earlier, when housed in groups, dominant sows tend to stay in front of the feeder. Consequently, low-ranking sows may have initiated fewer approaches to the feeder after hearing an unknown sound to avoid sows from a higher hierarchical rank (Manteuffel et al., 2022), which may partly explain their higher success rate for unknown sounds. Further studies should consider a feeding sequence that fits the hierarchy of the sow group by giving access to the dominant sows before the subordinate sows, thus reducing subsequent blocking of the feeder by dominant sows (Manteuffel et al., 2022).

5. Conclusion

Our study suggests that gestating sows are capable of quickly learning to associate an individual sound to access to feed. Furthermore, we found some evidence that the sows were able to at least partially discriminate between the different sounds, although discrimination was not fully successful. Individual learning of a sound signal to access the feeder appears to reduce aggression between sows when tested in groups. Sows of low hierarchical rank learned and integrated the call-feeding strategy better than sows of high hierarchical rank, suggesting that this individual learning strategy may be more beneficial for them. Further studies should be conducted to improve this sound-call feeding strategy and the sows learning performance, by introducing a positive punishment to deter sows from presenting spontaneously to the feeder, and by implementing a feeding sequence based on social rank, with fixed feeding times. As the current protocol is time-consuming and requires sows to be moved every day, it is not likely to be applied to commercial systems. The protocol needs to be adapted so that learning can take place directly in the gestation room, with sounds automatically managed by a software included in the feeder.

CRediT authorship contribution statement

Anna Blanc: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Clémentine Deroiné:** Methodology, Investigation, Formal analysis, Data curation. **Caroline Clouard:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization. **Charlotte Gaillard:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank Carole Guérin, Patrick Touanel, Raphaël Comte, Manon De la Bourdonnaye and the staff from the experimental pig farm (Daniel Boutin, Yannick Surel and Manon Laurent) for helping during the experimental period.

Financial support

This work was supported by the French National Research Agency under the Investments for the Future Program, referred as ANR-16-CONV-0004 (#DIGITAG), and from INRAE, PHASE department.

References

Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67 (1), 1–48. https://doi.org/10.18637/jss.v067.i01.

Bench, C.J., Rioja-Lang, F.C., Hayne, S.M., Gonyou, H.W., 2013. Group gestation sow housing with individual feeding—II: how space allowance, group size and composition, and flooring affect sow welfare. Livest. Sci. 152, 218–227. https://doi.org/10.1016/j.livsci.2012.12.020.

Durand, M., Dourmad, J.-Y., Largouët, C., Tallet, C., Gaillard, C., 2021. Alimentation de précision des truies gestantes: prise en compte de la santé, du comportement et de l'environnement. INRAE Prod. Anim. 34, 293. https://doi.org/10.20870/productions-animales.2021.34.4.5369.

Ernst, K., Puppe, B., Schön, P.C., Manteuffel, G., 2005. A complex automatic feeding system for pigs aimed to induce successful behavioural coping by cognitive adaptation. Appl. Anim. Behav. Sci. 91, 205–218. https://doi.org/10.1016/j.applanim.2004.10.010.

Fox J., Weisberg S. (2019). _An R Companion to Applied Regression_, Third edition. Sage, Thousand Oaks CA. 〈https://socialsciences.mcmaster.ca/jfox/Books/Companion/〉.

Gaillard, C., Durand, M., Largouët, C., Dourmad, J.-Y., Tallet, C., 2021. Effects of the environment and animal behavior on nutrient requirements for gestating sows: future improvements in precision feeding. Anim. Feed Sci. Technol. 279, 115034 https://doi.org/10.1016/j.anifeedsci.2021.1150344.

Garrido-Izard, M., Correa, E.C., Requejo, J.M., Villarroel, M., Diezma, B., 2022. Cleansing data from an electronic feeding station to improve estimation of feed efficiency. Biosyst. Eng. 224, 361–369. https://doi.org/10.1016/j.biosystemseng.2022.11.004.

Horback, K.M., Pierdon, M.K., Parsons, T.D., 2016. Behavioral preference for different enrichment objects in a commercial sow herd. Appl. Anim. Behav. Sci. 184, 7–15. https://doi.org/10.1016/j.applanim.2016.09.002.

Hunter, E.J., Edwards, S.A., Simmins, P.H., 1989. Social activity and feeder use of a dynamic group of 40 sows using a sow-operated computerised feeder, 90–90 Proc. Br. Soc. Anim. Prod. 1989. https://doi.org/10.1017/S0308229600010825.

Illmann, G., Schrader, L., Špinka, M., Šustr, P., 2002. Acoustical mother-offspring recognition in pigs (Sus scrofa domestica). Behaviour 139, 487–505. https://doi.org/10.1163/15685390260135970.

Kirchner, J., Manteuffel, G., Schrader, L., 2012. Individual calling to the feeding station can reduce agonistic interactions and lesions in group housed sows. J. Anim. Sci. 90, 5013–5020. https://doi.org/10.2527/jas.2011-4478.

Kirchner, J., Manteuffel, C., Manteuffel, G., Schrader, L., 2014. Learning performance of gestating sows called to the feeder. Appl. Anim. Behav. Sci. 153, 18–25. https://doi.org/10.1016/j.applanim.2014.01.008.

Kramer, C.Y., 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12, 307–310. https://doi.org/10.2307/3001469.

Lanthony, M., Danglot, M., Špinka, M., Tallet, C., 2022. Dominance hierarchy in groups of pregnant sows: characteristics and identification of related indicators. Appl. Anim. Behav. Sci. 254, 105683 https://doi.org/10.1016/j.applanim.2022.105683.

Lawrence, A.B., Appleby, M.C., Macleod, H.A., 1988. Measuring hunger in the pig using operant conditioning: the effect of food restriction. Anim. Prod. 47, 131–137. https://doi.org/10.1017/S0003356100037132.

Lenth R. (2023). _emmeans: Estimated Marginal Means, aka Least-Squares Means_. R package version 1.8.8, ⟨https://CRAN.R-project.org/package=emmeans⟩.

Mahnhardt, S., Brietzke, J., Kanitz, E., Schön, P.C., Tuchscherer, A., Gimsa, U., Manteuffel, G., 2014. Anticipation and frequency of feeding affect heart reactions in domestic pigs1. J. Anim. Sci. 92, 4878–4887. https://doi.org/10.2527/jas.2014-7752.

Manteuffel, G., Langbein, J., Puppe, B., 2009. Increasing farm animal welfare by positively motivated instrumental behaviour. Appl. Anim. Behav. Sci. 118, 191–198. https://doi.org/10.1016/j.applanim.2009.02.014.

Manteuffel, G., Mannewitz, A., Manteuffel, C., Tuchscherer, A., Schrader, L., 2010. Social hierarchy affects the adaption of pregnant sows to a call feeding learning paradigm. Appl. Anim. Behav. Sci. 128, 30–36. https://doi.org/10.1016/j.applanim.2010.10.002.

Manteuffel, C., Puppe, B., Hartwig, T., Wirthgen, E., 2022. Learning, health and productivity of group-housed sows conditioned to signal-feeding under realistic husbandry conditions. Livest. Sci. 266, 105111 https://doi.org/10.1016/j.livsci.2022.105111.

Milgram, N.W., 2003. Cognitive experience and its effect on age-dependent cognitive decline in beagle dogs. Neurochem Res 28, 1677–1682. https://doi.org/10.1023/A:1026009005108.

Norring, M., Valros, A., Bergman, P., Marchant, J.N., Heinonen, M., 2019. Body condition, live weight and success in agonistic encounters in mixed parity groups of sows during gestation. Animal 13, 392–398. https://doi.org/10.1017/S1751731118001453.

Puppe, B., Ernst, K., Schön, P.C., Manteuffel, G., 2007. Cognitive enrichment affects behavioural reactivity in domestic pigs. Appl. Anim. Behav. Sci. 105, 75–86. https://doi.org/10.1016/j.applanim.2006.05.016.

R Core Team (2023). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. ⟨https://www.R-project.org/⟩.

Rioja-Lang, F.C., Connor, M., Bacon, H.J., Lawrence, A.B., Dwyer, C.M., 2020. Prioritization of farm animal welfare issues using expert consensus. Front. Vet. Sci. 6, 495. https://doi.org/10.3389/fvets.2019.00495.

Sonoda, L.T., Fels, M., Rauterberg, S., Viazzi, S., Ismayilova, G., Oczak, M., Bahr, C., Guarino, M., Vranken, E., Berckmans, D., Hartung, J., 2013. Cognitive enrichment in piglet rearing: an approach to enhance animal welfare and to reduce aggressive behaviour. ISRN Vet. Sci. 2013, 1–9. https://doi.org/10.1155/2013/389186.

Tallet, C., Courboulay, V., Devillers, N., Meunier-Salaün, M.-C., Prunier, A., Villain, A., 2020. Mieux connaître le comportement du porc pour une bonne relation avec les humains en élevage. INRA Prod. Anim. 33, 81–94. https://doi.org/10.20870/productions-animales.2020.33.2.4474.

Tallet, C., Linhart, P., Policht, R., Hammerschmidt, K., Šimeček, P., Kratinova, P., Špinka, M., 2013. Encoding of situations in the vocal repertoire of piglets (Sus scrofa): a comparison of discrete and graded classifications. PLOS ONE 8, e71841. https://doi.org/10.1371/journal.pone.0071841.

Van De Weerd, H., Ison, S., 2019. Providing effective environmental enrichment to pigs: how far have we come? Animals 9, 254. https://doi.org/10.3390/ani9050254.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, Fourth edition. Springer, New York. ISBN 0-387-95457-0.

Verdon, M., Hansen, C.F., Rault, J.-L., Jongman, E., Hansen, L.U., Plush, K., Hemsworth, P.H., 2015. Effects of group housing on sow welfare: a review1. J. Anim. Sci. 93, 1999–2017. https://doi.org/10.2527/jas.2014-8742.

Wickham, H., 2009. ggplot2: Elegant Graphics For Data Analysis (use R!). Springer, New York. https://doi.org/10.1080/15366367.2019.1565254.

Wredle, E., Rushen, J., de Passillé, A.M., Munksgaard, L., 2004. Training cattle to approach a feed source in response to auditory signals. Can. J. Anim. Sci. 84, 567–572. https://doi.org/10.4141/A03-081.

Zebunke, M., Langbein, J., Manteuffel, G., Puppe, B., 2011. Autonomic reactions indicating positive affect during acoustic reward learning in domestic pigs. Anim. Behav. 81, 481–489. https://doi.org/10.1016/j.anbehav.2010.11.023.

Zebunke, M., Puppe, B., Langbein, J., 2013. Effects of cognitive enrichment on behavioural and physiological reactions of pigs. Physiol. Behav. 118, 70–79. https://doi.org/10.1016/j.physbeh.2013.05.005.

Zurbrigg, K., Blackwell, T., 2006. Injuries, lameness, and cleanliness of sows in four group-housing gestation facilities in Ontario. J. Swine Health Prod. 14, 202–206.