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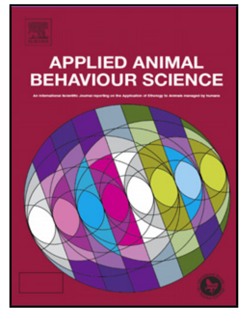

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Authors: Alessia Diana, Lenn Carpentier, Deborah Piette, Laura Ann Boyle, Daniel Berckmans, Tomas Norton

PII: S0168-1591(19)30035-8
DOI: https://doi.org/10.1016/j.applanim.2019.03.011
Reference: APPLAN 4790

To appear in: *APPLAN*

Received date: 10 December 2018
Revised date: 5 March 2019
Accepted date: 10 March 2019

Please cite this article as: Diana A, Carpentier L, Piette D, Boyle LA, Berckmans D, Norton T, An ethogram of biter bitten pigs during an ear biting event: first step in the development of a Precision Livestock Farming tool, *Applied Animal Behaviour Science* (2019), https://doi.org/10.1016/j.applanim.2019.03.011

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An ethogram of biter bitten pigs during an ear biting event: first step in the development of a Precision Livestock Farming tool

Alessia Diana[a,b,§] alessiadiana84@gmail.com**, Lenn Carpentier**[c,§] lenn.carpentier@kuleuven.be**, Deborah Piette**[c] deborah.piette@kuleuven.be**, Laura Ann Boyle**[a*] laura.boyle@teagasc.ie**, Daniel Berckmans**[c] daniel.berckmans@kuleuven.be**, Tomas Norton**[c] tomas.norton@kuleuven.be

[a]Pig Development Department, Teagasc Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, P61 0996, Ireland;

[b]School of Veterinary Medicine, University College Dublin, Belfield, Dublin 4, D04 W6F6, Ireland;

[c]M3-BIORES KU Leuven, Department BioSystems, Kasteelpark Arenberg 30 – 3001 Heverlee, Belgium.

[*]**Corresponding author at**: Pig Development Department, Teagasc Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, P61 0996, Ireland;; phone: + 353 (0)2542389

§These authors contributed equally to this work.

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Highlights

- Two ethograms (biter/bitten pig) to describe the behavioural repertoire are proposed
- Six types of behaviours were identified for the biter pig
- Four non-vocal and three vocal responses were identified for the bitten pig
- A decision tree yielded a precision of 83.2% in distinguishing the vocal behaviours
- Results suggests potential to develop a PLF tool to monitor ear biting behaviour

Abstract

Pigs reared in intensive farming systems are more likely to develop damaging behaviours such as tail and ear biting (EB) due to their difficulty in coping with the environment and their inability to perform natural behaviours. However, much less is known about the aetiology of EB behaviour compared to tail biting behaviour. Application of new intervention strategies may be the key to deal with this welfare issue. The discipline of Precision Livestock Farming (PLF) allows farmers to improve their management practices with the use of advanced technologies. Exploring the behaviour is the first step to identify reliable indicators for the development of such a tool. Therefore, the aim of this study was to develop an ethogram of biter and bitten pigs during an EB event and to find potential features for the development of a tool that can monitor EB events automatically and continuously. The observational study was carried out on a 300 sow farrow-to-finish commercial farm in Ireland (Co. Cork) during the first and second weaner stages. Three pens per stage holding c. 35 pigs each, six pens in total, were video recorded and 2.2 h of videos per pen were selected for video analysis. Two ethograms were developed, one for the biter and one for the bitten pig, to describe their behavioural repertoire. Behaviours were audio-visually labelled using ELAN and afterwards the resulting labels were processed using MATLAB® 2014. For the video data, duration and frequency of the observed behavioural interactions were quantified. Six behaviours were identified for the biter pig and a total of 710 interactions were observed: chewing (215 cases), quick bite (138 cases), pulling ear (97 cases), shaking head (11 cases), gentle manipulation (129 cases) and attempt to EB (93 cases). When the behaviour observed was not certain, it was classified as doubt (27 cases). Seven behaviours were identified for the bitten pig in response to the biters behaviour

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and were divided in: four non-vocal behaviours described as biting (40 cases), head knocking (209 cases), shaking/moving head (225 cases) or moving away (156 cases); and three vocal behaviours identified as scream (74 cases), grunt (166 cases), and squeal (125 cases). Vocal behaviours were classified using a verified set of features yielding a precision of 83.2%. A significant difference in duration was found between all the behaviours ($P < 0.001$), except between gentle manipulation and chewing where no difference in duration was found ($P < 0.338$). The results illustrate the heterogeneity of EB behaviours, which may be used to better understand this poorly studied damaging behaviour. They also indicate potential for the development of a PLF tool to automatically, continuously monitor such behaviour on farm by combining the behaviour of the biter pig and the bitten pigs responses.

Keywords

Damaging behaviour; Bioacoustics; Ear biting; Labelling; Pig; Vocalisations

1. Introduction

Pigs unable to cope with their environment and unable to perform their natural behavioural repertoire are at risk of developing ‘abnormal’ or ‘damaging’ behaviours (Wiepkema, 1984; Fraser & Broom, 1997). These include tail, ear and flank biting which see the involvement of two pigs [i.e. biter and bitten pig - (Zonderland et al., 2010)] and result in lesions on the body (Blackshaw, 1981). Pigs exhibiting these behaviours are usually reared in intensive farming systems where high stocking densities, mixing of pigs and a barren environment are major risk factors (Petherick & Blackshaw, 1987; Schroder-Petersen & Simonsen, 2001; Van de Weerd et al., 2006). Hence these behaviours not only cause poor welfare but also reflect poor pig welfare in the performer (Schroder-Petersen & Simonsen, 2001). Specifically, there are reports that ear biting (EB) seems to be a welfare issue of growing importance on intensive pig farms (Smulders et al., 2008, Meer et al., 2017). For instance, van Staaveren et al. (2018) found that on a sample of 31 farms in Ireland, 100% of the farms and 57% of the total pens observed had at least one pig affected by ear lesions. While, Meer et al. (2017) found that EB was scored more frequently than tail biting behaviour. It is possible that EB becomes

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more frequent when tails are short-docked (Goossens et al., 2008), a common practice still applied in several EU countries to limit tail biting damage (D'Eath et al., 2016), redirecting pigs oral manipulation from tails to ears. Therefore, in spite of suggestions of tail and EB being linked, with tail biting pigs also showing more EB (Brunberg et al., 2011; Telkänranta et al., 2014), it appears that other factors or perhaps motivational bases may be important in determining whether an outbreak of one or the other behaviour occurs.

Although little is still known about its development, EB appears to begin during the weaner stage (with pigs being c. 5 to 12 weeks old). Though not well elucidated, EB is associated with ear necrosis lesions (Richardson et al., 1984; Park et al., 2013). These appear not long after weaning, and generally in pigs which range from 2 to 3 weeks post weaning (Mirt, 1999; Pringle et al., 2009; Park et al., 2011). However, lack of robust research on this behaviour and on the resulting lesions poses a challenge in trying to address this welfare issue.

The pig industry is moving towards an era of more prudent antibiotic usage (EU Parliament, 2018) which will likely see the need for a significant reduction in the prophylactic use of antibiotics. Diana et al. (2017) reported that pigs with in-feed prophylactic antibiotics were less likely to have ear lesions than their counterparts without such medications suggesting that it had a curative effect. This raises concerns for farms with EB/ear lesion problems in the event of a withdrawal of in-feed medication and hastens the need to develop strategies to help prevent or reduce this damaging behaviour.

The field of Precision Livestock Farming (PLF) allows farmers to optimise their management practices with the use of advanced technologies (Guarino et al., 2017). Automatic, continuous monitoring of herds in real-time permits farmers to take prompt action when an issue arises on farm (Wathes et al., 2008). A first step in building an automatic monitoring system is to identify reliable indicators, such as a specific movement or sound, which could be used as feature variables for the development of an algorithm (Tullo et al., 2017). Understanding the behaviour is then fundamental because specific behavioural patterns may be involved before and during an EB event, as already found for aggressive interactions between pigs (McGlone, 1985). The early signs (behaviours) can be automatically detected using image analysis to serve as a warning tool for

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stakeholders (Oczak et al., 2013 ;Viazzi et al., 2014; Nasirahmadi et al., 2016). In addition, the vocal behaviour of pigs has been well studied during different situations such as pain (Marx et al., 2003), suckling (Jensen and Algers, 1983), cold (Hillmann et al., 2004; Cordeiro et al., 2013) and warm (Ferrari et al., 2013) temperatures. Different approaches were already applied for the automatic detection of some of the aforesaid vocalisations. For instance, the automatic monitoring of respiratory health (Hemeryck et al. 2014) and the monitoring of stress vocalisations such as screams (Schön et al., 2001; Schön et al. 2004; Vandermeulen et al., 2015). Therefore, PLF technologies may be of help in the development of intervention strategies to both detect and potentially predict EB behaviour. The ability to detect and/or predict the onset of EB behaviour could facilitate early intervention to prevent such behaviour from escalating. To our knowledge, a description of the vocal and non-vocal behavioural repertoire [i.e. ethogram - (Banks, 1982)] performed by the subjects involved in an EB event has never been done before. Such an exploration would not only yield information on a poorly studied behaviour but could also help to identify reliable behavioural features to design a PLF algorithm.

Therefore, the aim of this study was to identify and describe the behaviours performed by biter and bitten pigs during an EB event in order: 1) to develop an ethogram of this damaging behaviour and 2) to find potential reliable behavioural features for the development of an algorithm to monitor the occurrence of EB behaviour automatically and continuously.

2. Material and methods

2.1 Animals and housing

The study was carried out on a 300 sow farrow-to-finish commercial farm with a history of EB behaviour, located in Co. Cork, Ireland. The farmer was willing to cooperate with the video data collection required for the study and the procedure was approved by the Teagasc Animal Ethics Committee (TAEC 40/2013). As this was an observational study, pigs (Large White × Landrace) were managed according to usual farming practice. Hence, pigs were weaned at 28 ± 2 days of age and spent 4 weeks in the first stage weaner accommodation, 4 weeks in the second stage weaner accommodation and from 8 to 11 weeks in the finishing stage depending on the time required to

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reach slaughter weight (c. 110kg). Specifically, at weaning pigs were assigned to a pen (3 m L x 2.4 m W) holding about 35 pigs and the same group was later transferred to the second stage weaner accommodation (6 m L x 2.9 m W). Finally, pigs were re-mixed into groups of c. 23 pigs and moved to the finisher accommodation. For the current study, observations were only carried out on pigs in the first and second stage weaner accommodation.

Rooms for each weaner stage had an automatic temperature control system and they were artificially illuminated from 08.00 till 17.00 h. Ventilation was provided by a mechanical system comprising central chimney fans in the ceiling, with the temperature being controlled to a recommended average of 26˚C for the first weaner stage and 22.5°C for the second weaner stage. Pigs were housed on fully slatted floors with solid plastic panel pen divisions. All pens had at least one nipple drinker with *ad libitum* water provided. Pigs were fed *ad libitum* by a SPOTMIX liquid feeding system (Schauer Agrotronic GmbH, Prambachkirchen, Austria) and pens were furnished with environmental enrichments in the form of one rubber helicopter toy (EasyFix™ Rubber Products, Ballinasloe, Co. Galway, Ireland) and one strip (approximately 1 m long) of plastic based sack 'cloth' suspended from the side of the pen by a plastic cable tie.

2.2 Experimental design and installations

Video recording was used to collect data on EB events. Two cameras (Panasonic®, model HC-V250EB-K) were used, one for each weaner stage which were placed above the pen in a lateral position at a height of approximately 2 m, so that a full-view of the experimental pen was attained. Camera resolution was 1280 x 720 pixels and videos were stored on a computer for later analysis. Stereo sound was captured on the video with a sampling frequency of 48 kHz. To reduce the file size, video files were compressed using MPEG-4 standard. For the study, six different pens of c. 35 grower pigs, three for each of the two weaner stages, were randomly selected. Behaviour was recorded once for each of the 3 pens during each weaner stage. Recording took place throughout one day (i.e. from 09.30 to 17.30). In detail, behaviour was recorded during the first weaner stage on one day for one pen in week 1, for one day in the second pen in week 2 and for one day in the third pen in week 4 post weaning, to give a total of 3 days of recording (24 hours in total) for the first weaner

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stage. Recording was organised in a similar manner during the second weaner stage, once for one pen in week 6, once for a second pen in week 7 and once for a third pen in week 8 post weaning. Finally, 2.2 h of video recordings per day were selected for video analysis based on the time in which the highest level of activity was observed in that pen yielding a total of 13.2 hours for analysis.

2.3 Video observations and labelling procedure

Videos were observed by an ethologist trained to identify all behavioural interactions involving ear directed behaviour including EB events. An EB event was classified as an interaction between two pigs, defined as biter and bitten pigs, where the first performed a sustained mastication of a penmate's ear accompanied by a response in the pig being bitten. The event was considered finished when physical contact between the two pigs was lost for at least one second. Each interaction was carefully observed to describe the type of behaviour or body position displayed by the two subjects involved in the behavioural event. A review of all the interactions observed facilitated the development of the ethograms. Hence, two ethograms were developed to describe the behavioural repertoire performed during an interaction by the two pigs, one for the biter and one for the bitten pig (See Table 1 and 2). Each ethogram constituted categories and types of behaviours.

The recorded videos were labelled by one observer according to the ethograms developed using 'ELAN' version 4.9.4 Windows (Brugman & Russell, 2004) software. ELAN is a specialised software that allows a multimodal and multipurpose annotation system (Brugman & Russell, 2004). The labelling procedure is an important step for the identification of any type of behaviour performed during an established period of time. The procedure required the labeller to manually annotate the behaviour observed in each image (e.g. the type of behaviour/body position performed during and EB event) and to determine the starting point of an EB event and its duration. When a variable was detected on the video, the appropriate button or annotation was selected/typed on the ELAN interface (Tullo et al., 2017) and matched to the subject being observed (i.e. biter or bitten pig). In fact, for this study two different subjects were labelled at the same time on the same software interface (i.e. biter and bitten pigs during an EB event). The labelling procedure took about 148 hours for 13.2 h of video recordings.

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2.4 Analysis

ELAN allowed the export of data to different file formats including text files. Text files were later processed using MATLAB® 2014 (The MathWorks Inc., Natick, MA). Behavioural categories were not quantified; hence descriptive statistics were not calculated. Instead, the types of behaviours were quantified as events in terms of duration and frequency and descriptive statistics were carried out. This allowed us to calculate the frequency and duration of each behaviour performed by biter and bitten pigs during an EB interaction. Frequency is presented as the percentage of the total number of the behavioural events while duration results were reported as means ± standard error (SE).

In addition to the descriptive analysis of each behavioural type, a statistical test was applied to examine whether the duration of the behavioural types were significantly different from each other. First, it was checked if the data had a normal distribution using the Lilliefors test. Second, the equality of the variances was tested using the Levene's test (Trujillo-Ortiz, 2003). Depending on the distribution and variance of the data different statistical tests were used. The two sample t-test was used when the data had normal distributions and normal variances. The Welch's ANOVA test was used when there was a normal distribution and non-homogeneity of variances (Trujillo-Ortiz, 2012). While the Wilcoxon test was used if the data had no normal distributions and normal variances. Both the two sample t-test and Wilcoxon test were applied when the data had no normal distributions and no homogeneity of variances. Results were presented by their corresponding P-value. When the number of observations was smaller than 25 statistical tests were not carried out. For all tests, the criterion for statistical significance was established at $P < 0.05$ and statistical trends were reported $0.05 > P < 0.10$.

A decision tree (Fig. 1) approach was used to classify sounds (e.g. squeal, grunt, acute) that could be linked with specific behavioural states of the pigs during EB. Sound features were calculated for each individual sound event (e.g. grunt) on one channel of the stereo sound. For the decision tree five different features were used: duration, mean frequency, 10th percentile frequency, mean spectral spread and 10th percentile spectral flux. All features were calculated on the manual annotated sound events, beginning and ending of the sound event were annotated by the labeller.

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Duration (x1) was defined as the end of a sound event minus the beginning and was expressed in seconds. All six other features were based on the spectrogram (Fig. 2b) of the sound event. The spectrogram was calculated with a window size of 512 samples and 256 samples overlap. To calculate both the median and 10th percentile frequency, the short-time Fourier spectra (Fig. 2a) were summed over time which resulted in a frequency vector containing the aggregated energy (Fig. 2c). The mean frequency (x2) is the average frequency of the aggregated energy vector and was expressed in Hz. The 10th percentile frequency (x3) was the frequency for which 10% of the aggregated energy was below it and was also expressed in Hz.

Both the spectral spread and spectral flux features were calculated from each short-time Fourier spectra. The spectral spread (Equation 1) represented how well the energy was clustered around its centroid (Equation 2).

$$C = \frac{\sum_{k=1}^{Wf_L} kX(k)}{\sum_{k=1}^{Wf_L} X(k)} \qquad (1)$$

$$S = \sqrt{\frac{\sum_{k=1}^{Wf_L} (k-C)^2 X(k)}{\sum_{k=1}^{Wf_L} X(k)}} \qquad (2)$$

Where X(k) represented the energy of the kth frequency bin (k = 1 … Wf_l). The mean (x4) of the vector containing the spectral spreads of each short-time Fourier spectrum was used as feature.

The spectral flux (Equation 3) quantified how much two consecutive short-time Fourier spectra deviate from each other. The 10th percentile frequency (x5) was used as feature.

$$Fl_{(i,i-1)} = \sum_{k=1}^{Wf_L} (X_i(k) - X_{i-1}(k))^2 \qquad (3)$$

To train the decision tree 66.6% of the data (238 sound samples) were used. The remaining 33.3% (119 sound samples) were used for validating the decision tree. The performance was shown in a confusion matrix and the precision (Equation 4) was calculated.

$$precision = \frac{number\ of\ true\ positives}{number\ of\ true\ positives + number\ of\ false\ positives} \qquad (4)$$

3. Results

3.1 The ethograms

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Biter pig ethogram – Six different types of behaviour were identified and described for the biter pig: quick biting, shaking head, pulling the ear, chewing, gentle manipulation, and EB attempt (Fig. 3). Each behaviour was classified into a specific category in order to distinguish between 'EB events' (i.e. the biter pig performs a sustained mastication of a penmate's ear accompanied by a response of the bitten pig) and those not considered an EB event because the event was not completed, i.e. the interaction did not result in full biting or in full biting with response. Hence, within the behaviours listed above, quick biting, shaking head, pulling the ear and chewing were categorised as 'Ear in the mouth with response'; gentle manipulation was categorised as 'Ear in the mouth with no response' with the final category being 'EB attempt'. Description and classifications of the behaviours are presented in Table 1.

Bitten pig ethogram - Seven different types of behaviour were identified and described for the bitten pig, which were split into four non-vocal behaviours [head knocking, shaking/moving head away, moving away, and biting (Fig. 3)] and three vocal behaviours [scream (Fig. 4a), grunt (Fig. 4b), and squeal (Fig. 4c)]. Each behaviour describes the type of response expressed by the bitten pig during an EB event and they were also classified into a category according to the type of response of the bitten pig. Hence, within behaviours listed above head knocking and biting were categorised as 'Aggressive non-vocal response', shaking/moving head away and moving away are classified as 'Avoidance non-vocal response' while all the vocal behaviours were classified as 'Vocal response'. Description and classification of the behaviours are presented in Table 2.

3.2 Frequency and duration of behaviours

A total of 710 interactions (i.e. including both those classified as real 'EB events' and those not considered an EB event) by the biter pig were observed during the 13.2 hours of video recording which included pigs in both the first and second weaner stages. Specifically, 500 interactions were identified during the first weaner stage and 210 during the second weaner stage. Out of the 500 interactions observed during the first weaner stage, 316 (63.2%) were classified as EB events while

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145 of 210 interactions (69.1%) were classified as EB events during the second weaner stage (Table 3).

Biter pig - Analysis of the six different behaviours performed by the biter pig revealed that chewing was the most frequently occurring behaviour during both the first (29.4%) and second (32.4%) weaner stages followed by quick bite (20.4%) for the first weaner stage and by gentle manipulation (22.4%) for the second weaner stage. Among the interactions classified as EB events, chewing behaviour was performed most frequently during both first (46.5%) and second (46.9%) weaner stages followed by quick bite (32.3%) and pulling ear (18.7%) during the first weaner stage and by pulling ear (26.2%) and quick bite (24.8%) during the second weaner stage. Those behaviours that were not classified as EB events accounted for 16.4% (gentle manipulation) and 15.4% (attempt to EB) of the overall interactions that occurred during the first weaner stage and for 22.4% (gentle manipulation) and 7.6% (attempt to EB) of the overall interactions that occurred during the second weaner stage (Table 3).

The results relating to the duration of the behaviours (Table 3) showed that chewing was the behaviour performed for longest with an average duration of 3.75 s during the first stage followed by gentle manipulation (3.53 s) and shaking head (2.62 s). During the first weaner stage all behaviours categorised as 'Ear in the mouth with response' (i.e. the EB event) with adequate number of observations (i.e. chewing, pulling ear and quick bite) were significantly different in duration from each other (chewing - pulling ear $P < 0.001$; chewing - quick bite $P < 0.001$; pulling ear – quick bite $P < 0.001$). Shaking head was observed only 8 times during the first weaner stage, hence no statistical test was applied. While, no difference was found between the duration of gentle manipulation and chewing ($P = 0.338$), as well as between the duration of attempt to EB and the duration of quick bite ($P = 0.793$). Conversely, gentle manipulation (3.41 s) was the behaviour performed for longest followed by chewing (2.87 s) and pulling ear (2.12 s) during the second weaner stage (Table 3). From the four behaviours categorised as 'Ear in the mouth with response' (i.e. chewing, quick bite, pulling ear and shaking head), no statistical tests were applied to shaking head as there were only three observations. The duration of chewing and pulling ear tended to be different ($P = 0.064$) while

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the duration between chewing and quick bite (P < 0.001) and pulling ear and quick bite (P < 0.001) were significantly different which was similar to the first weaner stage. Also, there was a tendency for a difference in duration between gentle manipulation and chewing (P = 0.063). A detailed overview of the P-values between the different behaviours for the first and second weaner stage can be found in Table 4.

Bitten pig - The findings for the four non-vocal and the three vocal behaviours were analysed separately. There could be none or multiple non-vocal or vocal behaviours linked with one EB event. First, the non-vocal behaviours performed by the bitten pig during the first weaner stage reveal that moving head (37.9%) was the most frequent behaviour followed by knocking head (32.6%) and moving away (23.2%). During the second weaner stage knocking head (34.3%) was the most frequently occurring behaviour followed by moving head (29.8%) and moving away (28.6%). Data are shown in Table 5.

Secondly, the vocal behaviours performed by the bitten pig reveal that grunts were emitted most commonly (29.5%) during the first weaner stage followed by squeal (21.2%) and scream (14.3%). During the second weaner stage the same order of behaviours was observed: grunt (28.4%), squeal (23.5%) and scream (10.4%). In both stages, more than a third of the sounds, 35.0% and 37.7% for the first and second weaner stage respectively, were labelled as 'doubt' since it was not possible to properly identify them due to the quality of the recorded sound.

The results related to the duration of non-vocal behaviours (Table 5) showed that moving away lasted the longest with an average duration of 1.38 s during the first stage followed by biting (0.84 s) and moving head (0.77 s). The same pattern was found during the second stage with moving away (1.64 s) lasting the longest followed by biting (0.80 s) and moving head (0.77 s). During the first weaner stage the duration of moving away was significantly different from the other behaviours (biting P < 0.001; head knocking P < 0.001; moving head P < 0.001), the duration of biting and moving head was also different (P = 0.019), while the duration of head knocking tended to differ with biting (P = 0.086) but not with moving head (P = 0.519). For the second weaner stage no tests were performed on the biting behaviour as there were only 13 observations of this behaviour. For

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the other behaviours the same conclusion was made. Detailed results on the P-values between the durations of behaviours are in Table 4. The results related to the duration of vocal behaviours (Table 5) showed that screams lasted the longest with an average duration of 1.24 s in the first weaner stage followed by grunts (0.72 s) and squeals (0.61 s). The same pattern was observed during the second weaner stage: scream (1.36 s), grunt (0.83 s), and squeal (0.69 s).

Relationship between biter behaviour and bitten pig response – The number and duration of each non-vocal and vocal behavioural response performed by the bitten pig associated with each of the behaviours performed by the biter pig during an EB event are presented in Tables 6 and 7, respectively. In the EB events observed during the first weaner stage where the biter pig performed chewing behaviour, the most frequent non-vocal response of the bitten pig was head knocking (n = 79) with an average duration of 0.74 s. The most frequent vocal response of the bitten pig was grunt (44) with an average duration of 0.79 s. However, many doubts were labelled (74) as it was often unclear which exact sound was emitted by the pig. In addition, when biter pigs performed pulling ear and shaking head behaviours, the most frequent non-vocal response of the bitten pig was to move away (n = 51 and 5, respectively) with an average duration of 1.47 s and 2.58 s respectively. In both cases also scream was observed as the most frequent response (n = 37 and 5, respectively), with an average duration of 1.31 s and 1.67 s respectively. The results also showed that moving head behaviour were the most frequent non-vocal response of the bitten pig when quick bite behaviour (51) and EB attempts (41) were performed by the biter pig with an average duration of 0.61 s and 0.52 s respectively (Table 6). The most frequent vocal response in both cases was grunt, (n = 32 and 20 times, respectively) with an average duration of 0.64 s and 0.75 s respectively. When the biter pig performed quick bite behaviour, the bitten pig often reacted with a squeal (29) which had an average duration of 0.68 s.

A similar pattern was found during the second weaner stage between the type of behaviour performed by the biter pig and the type of non-vocal responses of the bitten pig during an EB event (Table 6). For the vocal responses of the bitten pigs there were some differences. When the biter pig performed pulling ear there was no clear difference between the times the bitten pig reacted with a

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specific vocal behaviour. Also, when the biter pig performed quick bite more squeals (12) were labelled than grunts (6). For shaking head only three vocal responses were labelled (Table 7).

Overall, the results from both stages showed that chewing behaviour performed by the biter pig was mainly accompanied by a behavioural response categorised as ‘Aggressive response’ while pulling ear, quick bite and shaking head were mainly accompanied by a behavioural response categorised as ‘Avoidance response’. EB attempt evoked responses evenly divided between aggressive and avoidance responses (Table 6).

3.3 Classification of vocal behaviour of bitten pig

The vocal behaviour of the bitten pig consisted of three classes [scream, grunt, and squeal (Fig. 4)] classified using a decision tree (Fig. 1). The algorithm yielded a precision of 83.2%. A confusion matrix (Table 8) describing the correctly and falsely classified events showed that 12 out of 20 screams were recognised. Six of the scream sounds were falsely classified as squeals. 42 out of 50 grunts were correctly classified, five were wrongly classified as screams and three as squeals. From the squeal sounds 45 out of 49 were correctly classified and the remaining four were falsely classified as grunts.

4. Discussion

Behaviour is the first line in an animal’s defence against a stressor (Dawkins, 2004). Hence, automatically measured animal behaviour might be a particularly useful tool in helping farmers to monitor the performance, health and welfare of their animals (Fraser & Broom, 1997; Botreau et al., 2007). Understanding the behaviour is a first step in the development of an automatic monitoring system (Kashiha et al., 2013; Oczak et al., 2013). The objective of this study was to describe the behaviours performed by pigs during an EB event in order to identify reliable behavioural features that could potentially be used in the development of an algorithm to monitor EB behaviour on commercial pig farms.

In previous studies, authors assessed the frequency of occurrence of this type of damaging behaviour (Smulders et al., 2008; Brunberg et al., 2011; Telkänranta et al., 2014). However, none

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describe the specific behaviours associated with EB. The findings of the current study show that an EB event is characterised by a heterogeneous behavioural pattern (i.e. 13 different behaviours between the two subjects) where both biter and bitten pigs can perform the action differently. For the majority of the observed interactions, EB events were identified both during the first (63.2%) and second (69.1%) weaner stages. However, a third of the behaviours performed by the biter pig were identified as incomplete instances of EB either because the bitten pig did not react to the biting (i.e. gentle manipulation) or because the action of ear-in-the-mouth did not occur (i.e. attempt to EB). This indicates that the detection of incomplete EB events by a potential PLF monitoring tool should also be considered because they may provide useful information on the development of this damaging behaviour before the occurrence of a severe outbreak. For instance, it is accepted that prolonged gentle manipulation of the tail may not lead to an evident injury to the tail but can predispose those tails to damage for a future outbreak (Schrøder-Petersen et al., 2003).

4.1 Three approaches to explain EB behaviour

Better understanding of the aetiology of EB behaviour can be gained from increasing our knowledge about how EB behaviour is displayed. In their review on tail biting behaviour, Taylor and colleagues (2010) propose 3 different types of tail-biting based on the description of each type of biting behaviour, the potential motivation behind it and the conditions under each type of behaviour occurred. The first type described is called ‘two-stage tail-biting’ where biter pigs firstly go through a ‘pre-damage’ stage (i.e. manipulation causes no visible trauma to the tail and it is tolerated by the recipient pig with a passive or little response) followed by a ‘damaging’ stage where a more forceful dental manipulation breaks the skin leading to bleeding tails and to an avoidance response (Schrøder-Petersen et al., 2004). This motivational basis may relate to the pigs’ dissatisfied foraging and exploratory needs (Day et al., 1996). The second type of tail-biting is defined as ‘sudden-forceful tail-biting’ where the biter pig bites or forcefully yanks the tail of the recipient and this behaviour is considered an aggressive act due to frustration (Widowski, 2002). The motivational basis for this behaviour may be related to the pigs’ inability to access desired resources such as food. Finally, the

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third type of tail-biting, known as 'obsessive tail-biting', is described as 'fanatical' biting where the pig persistently look for tails to forcefully bite (Beattie et al., 2005).

According to the above description, we propose a similar framework for EB behaviour. For instance, the performance of chewing as the most frequently occurring behaviour during both weaner stages would suggest an association with an initial boredom or need for exploration which is naturally expressed by pigs through foraging and exploratory behaviours (Newberry et al., 1988). Indeed, chewing may be proposed as the resulting extension of gentle manipulation of the ear and eventually predispose to damage for future outbreaks as suggested for tail biting behaviour (Schrøder-Petersen et al., 2004; Taylor et al., 2010). To support such a hypothesis there is the average length of duration of these two behaviours. In fact, no difference is found between them (i.e. 3.75 s and 3.53 s) compared to the duration of the other types of behaviour. This suggests that gentle manipulation and perhaps in part also chewing may be associated with a non-harmful/non-damaging action as defined for tail biting (Taylor et al., 2010). Moreover, the authors also declare that 'two-stage tail-biting' and EB may have similar causes, which is supported by the data obtained in our study.

Similar to 'sudden-forceful tail-biting', we suggest that both pulling ear and shaking head behaviours may be associated with a state of frustration perhaps due to pigs' inability to access food or other resources. Indeed, these two behaviours are displayed as a vigorous bite or pull of the recipients ears and are often accompanied by blood (personal observations obtained through the video analysis) and a response by the bitten pig. This type of tail-biting is reported as either less easily seen or as rare (Taylor et al., 2010) which is consistent with the fact that pulling ear and shaking head behaviours was recorded less frequently in both the first (11.8% and 1.6%, respectively) and second weaner (18.1% and 1.4%, respectively) stages than chewing and gentle manipulation. Finally, data obtained from this study suggests that quick bite behaviour is more likely associated with the 'obsessive tail-biting' type. In fact, quick bite is shorter in duration (i.e. 0.63s) than pulling ear and shaking head behaviours, supporting the idea of a fanatical, persistent search for new ears to bite.

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The rationale for the above categorisation of EB is due to the similarity between ear and tail biting and their multifactorial nature (Brunberg et al., 2011). Hence, it may be that the classification of tail-biting behaviours into three different types each with a different motivational bases and perhaps a different aetiology of the behaviour may be appropriate to EB behaviour also.

4.2 Relationship between behaviour and response

In their review, Taylor et al. (2010) highlighted that the victims' response can change according to the type of discomfort or pain that they experience during a tail biting event. This is in agreement with our results which showed that chewing, a type of behaviour considered more tolerated and less painful for the bitten pig, is mainly accompanied by an 'aggressive response' by the bitten pig. A pig not experiencing a high degree of discomfort, might be more prone to act vigorously (i.e. biting, head knocking) to distract the attacker. Conversely, if the behaviour elicits a lot of pain they might be more likely to try to escape from the situation. Hence, this may explain why pulling ear, quick bite and shaking head are mainly accompanied by an 'avoidance response' showing that these three types of behaviour are associated with more serious pain for the bitten pig. To support our idea there are also the results related to vocal behaviours. The vocal response to chewing (mostly grunting) also indicates that this behaviour is less painful. The study of Marx et al. (2003) shows that screaming is more frequently expressed in painful situations which was the response mainly associated with pulling ear and shaking head in the current study. As a response to quick bites, grunts and squeals were expressed almost the same amount of times but fewer screams were detected. This may indicate that this behaviour is less painful than pulling ear and shaking head.

However, although different motivational bases may explain some of the behaviours performed by the pigs observed in the current study, the response towards an attempt to EB is more difficult to explain according to the motivational bases described by Taylor et al. (2010). Instead the concept of personality may be more useful (Forkman et al., 1995). It is well-known from the literature that personality influences animal behaviour and the way in which animals cope with stress (Dingemanse & Réale, 2005). For instance, Melotti et al. (2011) found that coping personality types in pigs are related to aspects of fighting and exploratory behaviours. They found that 'highly

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resistant' pigs [i.e. piglets that show more than two escape attempts when restrained by the hands of the researcher - (Bolhuis et al., 2003)] spent more time in self-initiated fights or bullying other pigs than 'lowly resistant' pigs [i.e. piglets that show fewer than two escape attempts when restrained by the hands of the researcher - (Bolhuis et al., 2003)]. These in turn prioritise exploration of enrichment materials over fighting. Hence, in our study pig personality may explain the different responses observed in the bitten pig when reacting to an 'attempt to EB' by the initiator. We observed approximately the same number of responses in both weaner stages between the two categories of non-vocal response: aggressive and avoidance. This may indicate that when an EB event is not completed, pigs may prefer to react in one way or another depending on their own personality and/or previous experiences, regardless of the type of discomfort associated with the EB event. Nonetheless, it is also likely that the responses applied by the bitten pig may also be dictated by the possible relationship of dominance/ submission established between biter and bitten pigs (Meese & Ewbank, 1973; Fels et al, 2014). Clearly further studies exploring pig personality and its relationship with damaging behaviours should be carried out to confirm this suggestion.

Overall, we suggest that all the identified behaviours can be used as valuable feature variables for the monitoring of EB events. However, we also recommend combining both the behaviour of the biter and the associated response of the bitten pig to develop a more powerful and reliable algorithm due to the fact that the type of response applied by the bitten pig may potentially indicate the severity of the EB event *per se*. Moreover, gentle manipulation should also be included as a feature variable in the algorithm as it may be used as a potential warning sign for the development of an EB outbreak. Based on this warning signal farmers could apply management strategies to mitigate or end the damaging behaviour. For instance, removing the biter or providing straw are effective in addressing tail biting outbreaks (Zonderland et al., 2008). Also, optimising the indoor climate (Geers et al., 1985) as well as pigs diet (Meer et al., 2017) are considered efficient approaches in reducing the occurrence of damaging behaviour.

4.3 Classification of vocal behaviours

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The features chosen in the decision tree indicate that calls uttered due to EB behaviour can be classified based on duration and frequency content. This is in line with the work of Marx et al. (2003) and von Borrel et al. (2009), who studied the vocal behaviour of pigs towards painful/stressful behaviour specifically their reaction towards castration. A similar precision (83.2%) for the classification was found in this study as in the work of von Borell et al. (2009) (86.7%) where two classification algorithms were compared with calibrated and non-calibrated measurements. Compared to the work of von Borell et al. (2009) less screams were found in this study than grunts and squeals. Screaming was a call type significantly different from the other vocalisations (Marx et al., 2003), hence parameters of duration and frequency content were considered appropriate to characterise these vocalisations. In addition, as for our study, the authors carried out observations during the entire weaner stage to take into account changes in the vocalisations due to the different age or weight of the pigs.

5. Conclusions

This first approach at exploring EB behaviour through the use of video analysis and labelling procedures led to an interesting insight into the heterogeneity of these behavioural events. Both biter and bitten pigs show a behavioural repertoire which may be used to better elucidate this poorly studied damaging behaviour. Our results also show that a combination of biter behaviours and responses of the bitten pig can be used as feature variables in the algorithm. In addition, the duration of the non-vocal behaviour and five features (duration, mean frequency, 10th percentile frequency, mean spectral spread and 10th percentile spectral flux) of the vocal behaviour are explored to automatically extract the feature variables from the video recordings. In conclusion, our findings indicate potential for the development of a PLF tool as an intervention strategy for the monitoring of EB behaviour and the prevention of its escalation.

AUTHORS DECLARATION

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

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We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from laura.boyle@teagasc.ie

Signed by all authors as follows:

Alessia Diana 04/12/2018

Lenn Carpentier 05/12/2018

Deborah Piette 05/12/2018

Laura Ann Boyle 05/12/2018

Daniel Berckmans 05/12/2018

Tomas Norton 05/12/2018

6. Declarations of interest

None.

7. Data statement

All data used and analysed during the current study are available from the corresponding author on reasonable request

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. **Data Statement**

I am not specifying any data sets because all data used and analysed during the current study are available from the corresponding author on reasonable request.

8. Acknowledgments

This project was supported by the Short Term Scientific Mission (STSM) under the COST Action (GroupHouseNet CA15134) EU Framework Programme Horizon 2020. We would like to thank the farm owner and staff for allowing us to carry out the study on his farm. We would also like to thank to Dr. Emanuela Tullo from the VESPA group, University of Milan, for her help in the labelling process. Alessia Diana was funded by the Teagasc Walsh Fellowship Fund and an internal Teagasc grant (reference 6497). Lenn Carpentier was funded through a KU Leuven internal research grant (3E170751).

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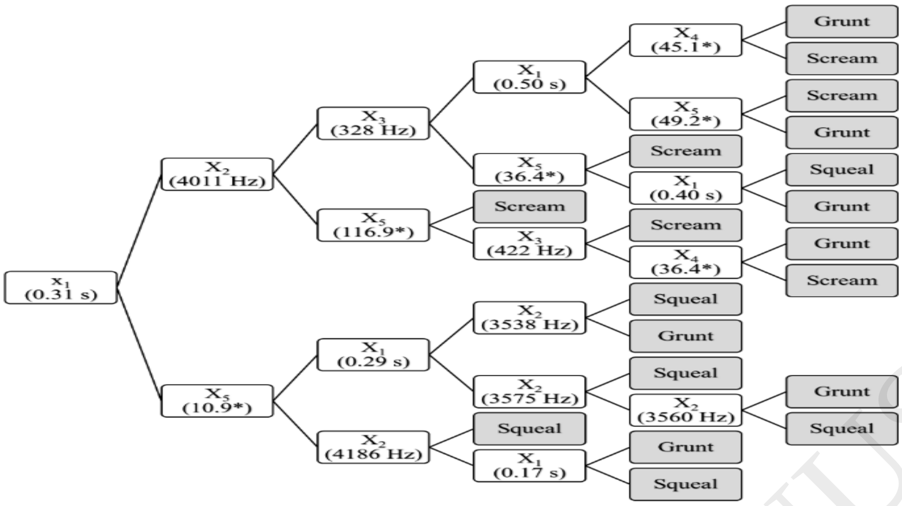
Fig. 1. Decision tree to classify the event based on the duration (x1), mean frequency (x2), 10th percentile frequency (x3), mean spectral spread (x4), and 10th percentile spectral flux (x5) of the sound. If the feature value of a sound is larger than or equal to the threshold the sound event moves to the next above branch if it is lower than it moves to the next branch below the tested node.



*Both x4 and x5 have the number of frequency bins as feature value. This can be converted to frequency by multiplying it with the sampling frequency (fs = 48 kHz) and dividing by the window size (512 samples).

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Fig. 2. Parameters were extracted from the spectrogram (b) of a selected sound (scream in this example). The spectral spread and flux were calculated for each short-time Fourier spectrum (a) and the mean (x2) and 10th percentile (x3) frequency were calculated from the aggregated frequency envelope (c).

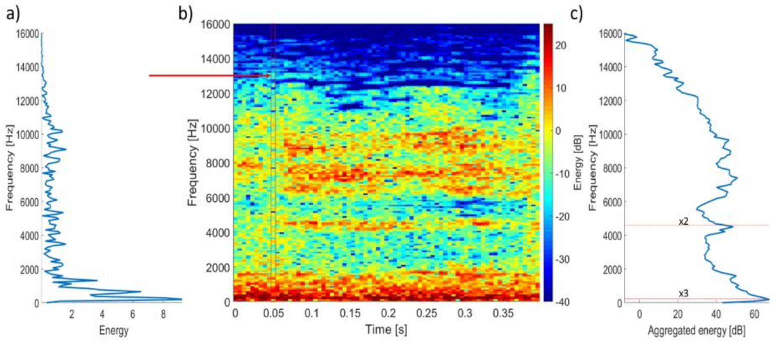

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Fig. 3. Examples of behaviours performed by the biter and bitten pigs during an ear biting event. The images were extrapolated from the software ELAN used for the labelling analysis. Biter pig (BR) behaviours: a) Chewing, b) Pulling ear, c) Quick bite. Bitten pig (BT) behaviours: d) Head knocking, e) Moving away, f) Biting.

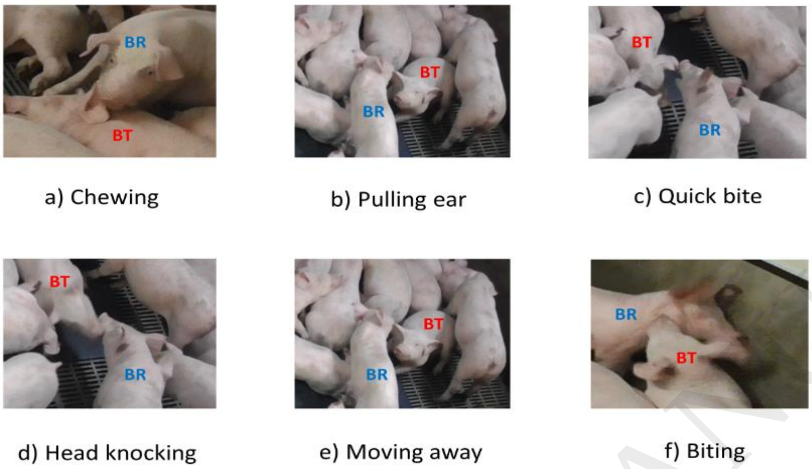

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Fig. 4. Spectrogram of a scream (a), grunt (b) and squeal (c) emitted by a bitten pig after an ear biting event.

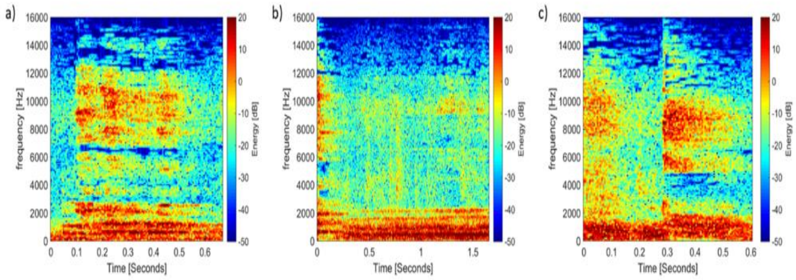

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Table 1. Ethogram of biter pig – list of behaviours performed by the biter pig during an interaction with another pig and used to carry out the labelling procedure

Behaviour category	Behaviour definition	Description
Ear in the mouth	Chewing	Prolonged mastication of the penmate's ear accompanied by a response of the pi
	Quick bite	Short duration bites directed towards penmate's ears (opening of its mouth ar another pig without any shaking of biter's body) accompanied by a response of t
	Pulling ear	Taking hold the ear of the penmate into its mouth and exerting force to move it a response of the pig being bitten
	Shaking head	Lateral movement of the head from one side to another one with the ear of accompanied by a response of the pig being bitten
Ear in the mouth with no response	Gentle manipulation	Soft chewing of the penmate's ear without any response from the pig being bitte
Attempt of ear biting (EB)	Attempt to ear bite	The actual behaviour (i.e. ear in the mouth) does not happen. It does not end u potential recipient pig seems aware about the risk of being bitten, hence it is more

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Table 2. Ethogram of bitten pig – list of behavioural responses performed by the bitten pig during an interaction with another pig and used to carry out the labelling procedure

Behaviour category	Behaviour definition	Description
Aggressive non-vocal response	Biting	Forceful and rapid bite toward the face of the biter pig with or without a vocalisat
	Head knocking	Forceful and rapid/quick vertical action/pushing of the head against the body of the going up and down, with or without a vocalisation response (Adapted from Jensen
Avoidance non-vocal response	Shaking/moving head	Lateral or vertical movement of the head from one side to another or from one sid biter penmate, with or without a vocalisation response
	Moving away	Moving or walking back (stretched front leg and hind-quarter lifted up) with the b the biter penmate with or without a vocalisation response
Vocal response	Scream	High frequency content calls with a large amplitude often uttered in stressful and (Jensen & Algers, 1984; Schrader & Todt, 1998; Puppe et al., 2005)
	Grunt	Low frequency calls with multiple formants call (Fig. 4b) (Jensen & Algers, 1984
	Squeal	Call with high (higher than screams) peak frequency and main frequency and short et al., 2003)

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Table 3. Number, percentage (%) and mean duration of the observed behaviours performed by the biter pig during an interaction
with another pig and collected during the first and second weaner stages.

Behaviour	First weaner stage				Second weaner stage			
	N	Percentage (%)	Mean duration (s)	SE	N	Percentage (%)	Mean duration (s)	SE
Chewing	147	29.4	3.75	0.26	68	32.4	2.87	0.35
Pulling ear	59	11.8	1.49	0.09	38	18.1	2.12	0.19
Quick bite	102	20.4	0.63	0.03	36	17.2	0.64	0.04
Shaking head	8	1.6	2.62	0.44	3	1.4	1.84	0.17
Gentle manipulation	82	16.4	3.53	0.33	47	22.4	3.41	0.38
Attempt of EB*	77	15.4	0.65	0.06	16	7.6	1.32	0.29
Doubt[1]	25	5.0	0.85	0.12	2	0.9	1.30	0.61
Total interactions	500	100			210	100		
Total EB events[2]	316	63.2			145	69.1		

[1] An event was labelled as 'doubt' when the researcher was not certain about the type of behaviour observed during the labelling
process and performed by the experimental pig.

[2] Sum of chewing, pulling ear, quick bite and shaking head behaviour events.

* Attempt of EB: Attempt of ear biting behaviour.

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Table 4. Statistical test to determine if the behaviours of the biter and bitten pigs differ in duration. No tests were applied to shaking
head behaviour as only 8 and 3 observations were identified during the first and second weaner stage, respectively.

Behaviour 1	**Behaviour 2**	**First weaner stage**	**Second weaner stage**
Biter pig			
Chewing	Pulling ear	P < 0.001	P = 0.064
Chewing	Quick bite	P < 0.001	P < 0.001
Chewing	Gentle manipulation	P = 0.338	P = 0.063
Chewing	Attempt of EB[2]	P < 0.001	N/A[1]
Pulling Ear	Quick bite	P < 0.001	P < 0.001
Pulling Ear	Gentle manipulation	P < 0.001	P = 0.004
Pulling Ear	Attempt of EB[2]	P < 0.001	N/A[1]
Quick bite	Gentle manipulation	P < 0.001	P < 0.001
Quick bite	Attempt of EB[2]	P = 0.793	N/A[1]
Gentle manipulation	Attempt of EB[2]	P < 0.001	N/A[1]
Bitten pig			
Biting	Head knocking	P = 0.086	N/A[1]
Biting	Moving away	P < 0.001	N/A[1]
Biting	Moving head	P = 0.019	N/A[1]
Head knocking	Moving away	P < 0.001	P < 0.001
Head knocking	Moving head	P = 0.519	P = 0.518
Moving away	Moving head	P < 0.001	P < 0.001

[1] N/A: Not Applicable indicating that there were less than 25 observations and no statistical test was applied.

[2] Attempt of EB: Attempt of ear biting behaviour.

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Table 5. Number, percentage (%) and mean duration of the observed behavioural response performed by the bitten pig
during an ear biting (EB) event and collected during the first and second weaner stages.

Behaviour		First weaner stage					Second weaner stage			
		N	Percentage (%)	Mean duration (s)	SE		N	Percentage (%)	Mean duration (s)	SE
Non-vocal total*		453	100				178	100		
Biting		27	5.9	0.84	0.069		13	7.3	0.80	0.057
Head knocking		148	32.7	0.74	0.031		61	34.3	0.75	0.039
Moving away		105	23.2	1.38	0.079		51	28.6	1.64	0.141
Moving head		172	37.9	0.77	0.053		53	29.8	0.77	0.059
Doubt[1]		1	0.3	3.92	N/A.		0	0	N/A	N/A
Vocal total*		386	100				183	100		
Scream		55	14.3	1.24	0.077		19	10.4	1.36	0.190
Grunt		114	29.5	0.72	0.034		52	28.4	0.83	0.058
Squeal		82	21.2	0.61	0.021		43	23.5	0.69	0.037
Doubt[2]		135	35.0	0.98	0.087		69	37.7	1.00	0.066

[1]A non-vocal behaviour was labelled as 'doubt' when the researcher was not certain about the type of behaviour observed
during the labelling process and performed by the experimental pig.

[2]A vocal behaviour was labelled as 'doubt' when it was unclear which sound the pig made because of the background
noise created by the other pigs and the machines inside the compartment

[*]Total number of behavioural responses is different from the total number of EB events observed by the biter pigs
(Table 3) for two reasons: 1. we do consider the responses applied by the bitten pig during an 'Attempt of EB';
2. A bitten pig may respond with no or multiple behaviours consecutively during the same EB event.

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Table 6. Number and mean duration of each non-vocal behavioural response performed by the bitten pig associated with each of the behaviours performed by the biter pig during an ear biting (EB) event; data collected during the first and second weaner stages.

Behaviour	First weaner stage			Second weaner stage		
	N	Mean duration (s)	SE	N	Mean[1] duration (s)	SE
Chewing						
Biting	24	0.84	0.077	10	0.75	0.059
Head knocking	79	0.74	0.036	33	0.81	0.046
Moving away	15	1.79	0.245	13	1.69	0.253
Moving head	59	1.09	0.132	21	0.92	0.104
Pulling ear						
Biting	1	0.84	N/A	0	N/A	N/A
Head knocking	4	0.42	0.062	5	0.85	0.266
Moving away	51	1.47	0.099	32	1.72	0.195
Moving head	7	1.01	0.105	4	0.99	0.244
Quick bite						
Biting	1	0.72	N/A	2	0.86	0.020
Head knocking	26	0.67	0.076	15	0.60	0.052
Moving away	25	0.73	0.060	3	0.76	0.197
Moving head	51	0.61	0.039	17	0.54	0.047
Shaking head						
Biting	0	N/A	N/A	0	N/A	N/A
Head knocking	0	N/A	N/A	0	N/A	N/A
Moving away	5	2.58	0.421	2	1.33	0.065
Moving head	1	2.59	N/A	1	1.35	N/A
Attempt of EB						
Biting	1	1.00	N/A.	1	1.20	N/A
Head knocking	31	0.73	0.076	7	0.815	0.139
Moving away	3	1.21	0.347	0	N/A	N/A
Moving head	41	0.52	0.050	10	0.74	0.137
Total interactions	426			176		

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Table 7. Number and mean duration of each vocal behavioural response performed by the bitten pig associated with each of the behaviours performed by the biter pig during an ear biting (EB) event; data collected during the first and second weaner stages.

Behaviour	First weaner stage			Second weaner stage		
	N	Mean duration (s)	SE	N	Mean duration (s)	SE
Chewing						
Scream	4	0.74	0.130	3	1.32	0.112
Grunt	44	0.79	0.065	30	0.89	0.088
Squeal	15	0.61	0.035	17	0.73	0.057
Doubt	74	1.10	0.149	28	1.02	0.112
Pulling ear						
Scream	37	1.31	0.079	13	1.47	0.238
Grunt	13	0.74	0.085	10	0.97	0.095
Squeal	14	0.59	0.037	13	0.72	0.058
Doubt	7	0.88	0.185	12	1.46	0.166
Quick bite						
Scream	5	0.83	0.076	2	0.60	0.085
Grunt	32	0.64	0.041	6	0.56	0.051
Squeal	29	0.68	0.043	12	0.60	0.034
Doubt	25	0.69	0.058	17	0.68	0.060
Shaking head						
Scream	5	1.67	0.539	0	N/A	N/A
Grunt	0	N/A	N/A	0	N/A	N/A
Squeal	2	0.51	0.011	1	1.45	N/A
Doubt	2	2.52	0.028	2	1.08	0.291
Attempt of EB						
Scream	0	N/A	N/A	0	N/A	N/A
Grunt	20	0.75	0.098	4	0.57	0.030
Squeal	11	0.49	0.031	0	N/A	N/A
Doubt	18	0.76	0.086	10	0.94	0.134
Total interactions	357			180		

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Table 8. Confusion matrix to visualise the real class and the decision tree predicted class.

		Real class			
		Scream	Grunt	Squeal	**Total**
Predicted class	Scream	12	5	0	**17**
	Grunt	2	42	4	**48**
	Squeal	6	3	45	**54**
	Total	**20**	**50**	**49**	

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