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The "Real Welfare" scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK

F. Pandolfi[a,*], I. Kyriazakis[a], K. Stoddart[b], N. Wainwright[b], S.A. Edwards[a]

[a] School of Agriculture Food and Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
[b] AHDB PORK, Stoneleigh Park, Kenilworth, CV8 2TL, UK

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ABSTRACT

From 2013–2016, animal-based measures were collected as part of the "Real Welfare" protocol adopted by the Red Tractor Pigs Assurance Scheme to assess the welfare in finisher pig herds in the UK. Trained veterinarians from 89 veterinary practices assessed 112,241 pens (hospital pens excluded) from 1928 farms using a multistage sampling protocol, and collected data about pig welfare, management and farm environment. Multivariable analyses were conducted for five main welfare outcomes: lameness, pigs requiring hospitalization, severe tail lesions, severe body marks and enrichment use ratio (number of active pigs interacting with the enrichment/total number of active pigs). Additionally, a multiple correspondence analysis (MCA) was conducted to analyse systematic patterns of variations of environmental characteristics and improve understanding of the connection between welfare outcomes and environment. The prevalence of the four welfare outcomes and the mean enrichment use ratio differed between pen types ($P < 0.05$), with a higher mean prevalence of lame pigs (0.39%) but lower mean prevalence of pigs requiring hospitalization (0.07%), severe tail lesions (0.07%) and severe body marks (0.12%) in outdoor pens. In&outdoor pens had the highest mean prevalence of the measured outcomes ($P < 0.05$). After adjusting for the farm, date and pen type, lameness, pigs requiring hospitalization and severe tail lesions were less prevalent in large pens ($P < 0.01$), pens with substrates ($P \leq 0.05$) and pens fed with meal ($P \leq 0.05$), while enrichment use ratio was higher with substrates ($P < 0.001$). Moreover, pigs requiring hospitalization and severe body marks were more prevalent in pens with powered ventilation ($P < 0.05$). On the MCA graph, higher prevalences of lameness and pigs requiring hospitalization (>1, 5 and 10%) were located in the same direction as lower enrichment use ratio, liquid feed, trough feeding, floor feeding, restricted feed and in&outdoor pens. Results suggested that higher prevalences were not specifically connected to a particular system, but that all welfare outcomes were connected to several inappropriate features in the environment. This study highlights individual risk factors which can be considered to improve animal welfare, but also indicates the need to consider the environment as a whole because of potential factor combinations and confounds. Understanding of these requires a large scale database, which can be drawn from assessments carried out as part of farm assurance and support evidence-based advice and future formulation of standards for good practice.

1. Introduction

Animal-based measures have been suggested to be more appropriate than resource –based measures to assess animal welfare (Whay et al., 2007). These measures, also called welfare outcomes, rely on measurements made on the animals themselves and are being adopted by Farm Assurance Schemes to benchmark animal welfare and promote welfare-friendly management (Blokhuis et al., 2010). Following pilot studies, the "Real Welfare" protocol for welfare outcome assessment was adopted by the Red Tractor Assurance Scheme for finisher pig herds in the UK. The welfare data were collected in conjunction with other data about enrichment provision, management practices and farm environment. Over three years, more than 90% of English pig farms were regularly visited (Pandolfi et al., 2017). This high population coverage and the probability sampling methodology permit scientifically-grounded estimates from the survey for the whole population of interest (Turner, 2003), and a previous descriptive analysis established mean values for five main welfare outcomes and their changes over time (Pandolfi et al., 2017).

* Corresponding author.
E-mail address: f.pandolfi@newcastle.ac.uk (F. Pandolfi).

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The data also constitute a valuable resource to identify risk factors related to the welfare outcomes. Risk or protective factors for tail biting, lameness or body lesions have been identified in previous studies (Hunter et al., 2001; Schroder-Petersen and Simonsen, 2001; Moinard et al., 2003; Van De Weerd et al., 2006; Temple et al., 2012; Munsterhjelm et al., 2015a). However, such studies generally refer either to experimental situations or farm samples which are not sufficiently large or representative to extrapolate the conclusions to the whole national population of pigs. Therefore, the data collected through the "Real Welfare" initiative provided the first opportunity to conduct a risk factor analysis on a large sample of finishing pig farms which can be considered as fully representative of the finishing pig farms present in the UK.

The objective of this study was to assess the multifactorial aspects of welfare issues by the identification of risk and protective factors at pen level, among variables related to pig environment and management, for five main welfare indicators: lameness, pigs requiring hospitalization, severe tail lesions, severe body marks and enrichment use. In the first instance, we identified risk factors for the five welfare outcomes with multivariable analyses. Subsequently, we used a multiple correspondence analysis to confirm and refine the results of the multivariable analyses and identify the relationship between pen environment and the severity of the different welfare outcomes. Finally, we interpreted the results to highlight the risk and protective factors which can be used to identify pen features connected to welfare issues and the critical points that should be the focus of veterinarians and farmers to improve the welfare of pigs in their care.

2. Materials and methods

2.1. Data and data management

The collection and management of the data used for this analysis have been described in detail in a previous publication (Pandolfi et al., 2017). The data were collected from April 2013 to May 2016 in order to assess on-farm pig welfare through the "Real Welfare" assessment protocol, as required for those finishing pigs under the Red Tractor Pigs Assurance Scheme. The assessment involved five main measures (Table 1) taken from a sample of pens on each farm during quarterly veterinary visits by trained vets from 89 different veterinary practices who underwent the same online and practical training. Detailed definitions of the five main measures can be found in the supplementary file of Pandolfi et al. (2017). Hospital pens were excluded from the assessment. All the measures reported in Table 1 were transformed into percentages, based on the total number of pigs assessed in the pen. Enrichment use was calculated as a ratio based on the following formula:

$$Enrichmentuseratio = \frac{Numberofactivepigsinteractingwiththeenrichment}{Numberofactivepigsinteractingwithpenfeaturesorpenmatesorwiththeenrichment}$$

Additional information about the sampled pens was also recorded during the visit (Table 2). The farm, from which the pens were sampled, and the date of the assessment were recorded for all pens.

For the complete database, a sample of pens was assessed from 1928 farm units. Repeated measures were taken in the same farm unit over three years, giving 112,240 records at pen level. The Real Welfare protocol was used to assess the prevalence of lameness and pigs requiring hospitalization on 5,463,348 pigs, the prevalence of body marks and tail lesions on 2,952,561 pigs and the enrichment use ratio (which was optional during the assessment) on 497,724 pigs.

Table 1
Measurements used by the veterinarians to assess welfare in commercial pig farms in the UK between 2013 and 2016 for the "Real Welfare" scheme.

Measurements Levels[a]	Definitions
Pigs requiring hospitalization	
Yes	Pigs that would benefit from removal to a hospital pen
No	Pigs that would not benefit from removal to a hospital pen.
Lame pigs	
Lame	Pigs with signs of lameness
Non lame	Pigs without any sign of lameness
Pigs with tail lesions	
Severe	Pigs with severe tail lesions. Proportion of tail has been removed by biting or tail is swollen or held oddly, or scab covering whole tip or fresh blood visible
Mild	Pigs with mild tail lesions
No lesions	Pigs without any of the above lesions
Dirty	Pigs dirty enough to obscure potential mild lesions
Pigs with body marks	
Severe	Pigs with severe body marks extending into deeper layers of skin or lesions covering a large percentage of skin
Mild	Pigs with mild body marks
No lesions	Pigs without any of the above body marks
Dirty	Pigs dirty enough to obscure potential mild body marks
Enrichment use Ratio (optional)[b]	
Enrichment	Pigs interacting with enrichment in the pen
Other	Pigs interacting with other pen features or pen mates

[a] Each pig in the sample selected was classified into one of the several levels for each measurement.
[b] The classification for enrichment use ratio only concerned the active pigs of the sample.

Table 2
Variables collected by the veterinarians at pen level to assess the environment in commercial pig farms in the UK between 2013 and 2016 for the "Real Welfare" scheme.

Variables	Categories
pen size	small <30 pigs
	medium ≥30 to <200 pigs
	large ≥200
pen type	indoor (kennels, open + internal divisions or open plan)
	outdoor (shelter + field)
	in&outdoor (trobridge or kennel + yard)
	other
ventilation	natural
	powered
feed form	pellets
	meal
	liquid
feed availability	ad libitum
	restricted
feeder type	floor
	hopper
	trough
tail docking	docked tails
	undocked tails
tail length	tail lengths ≤0.5 (pens with docked tails, smaller than half the original length)
	tail lengths >0.5 (pens with undocked tail, tails longer than half the original length or mixed tail lengths)
pig weight	<30 kg
	30–50 kg
	>50 kg
enrichment	substrate(s) only (straw or other substrates)
	object(s) only (chains, plastic objects or other objects)
	substrate(s) and object(s)
	no enrichment

2.2. Sampling

The sampling used was a multistage sampling. At the first level, all farms that finish pigs and belong to the Red Tractor Pigs Assurance Scheme were sampled. At the second level, several pens were randomly selected within each farm in order to be representative of the finisher pig places present in the farm (see Pandolfi et al., 2017 for pen sampling details, which are documented in full on the Scheme website http://pork.ahdb.org.uk/health-welfare/welfare/real-welfare/real-welfare-vets/). The assessments were carried out two to four times per year. For units of 300 finisher places or less, a minimum of 300 pigs were sampled each year, but for units of 900 finisher places or more, a total of 900 pigs were sampled per year. For units of between 300 and 900 finisher places, an equivalent representative proportion was sampled. As pen size could be different between farms and the number of pigs required depended on herd size, the number of pens selected differed between farms. At the third level, selected pens were assessed for all lame pigs and pigs requiring hospitalization and a random sample of pigs in the pen was further assessed for tail lesions and body marks (all pigs in the pen if there were fewer than 25 pigs, 25 pigs if there were up to 100 pigs, or 50 pigs if there were more than 100 pigs, and chosen to be representative of the pen). All the active pigs in the pens were assessed for enrichment use.

A retrospective power calculation was carried out for each welfare outcome, using the following equation (Teerenstra et al., 2008):

$$\mathrm{Deff} = (1 + \mathrm{ICC}(m - 1))$$

$$n'/\mathrm{Deff} = n$$

$$n = Z^2 \frac{(Z_{\alpha/2} + Z_\beta)2\sigma 2e^2}{}$$

The calculation was made for a desired margin of error (e) of 10% and 20% in the mean percentage of the welfare outcome and based on the actual sample size. We calculated the power of the analysis based on the sample size by accounting for the clustering effect of pens within farms. Therefore, we estimated the sample size n as the result of the actual sample size n' (the number of pens designated in the protocol) divided by the design effect Deff and we calculated the power based on the value of n. ICC is the intraclass correlation between pens within a farm and m the average number of pens per farm. The value of σ^2 (the population variance of the welfare outcome), e (margin of error) and ICC (intraclass correlation) were estimated from the descriptive analysis (Pandolfi et al., 2017). Zis the value from a standard normal distribution corresponding to the desired confidence level, with α as the type I error (Z = 1.96 for 95% CI) and β as the power of the analysis.

2.3. Data analysis

2.3.1. Influence of the environment on the welfare outcomes

First, the prevalence of the five main welfare outcomes was calculated for each pen type and their distribution was assessed for normality through the histograms. Kruskall Wallis tests with a Bonferonni correction were used to assess the differences between pen types. The influence of the other variables related to the environment on the different measures of welfare was assessed with a Generalized Linear Mixed Model in an analysis performed at pen level. Five different models were built, considering respectively as dependent variables: the proportion of pigs that would benefit from removal to a hospital pen, the proportion of lame pigs, the proportion of pigs with severe tail lesions, the proportion of pigs with severe body marks, the proportion of active pigs that interact with the enrichment in preference to other exploratory activities. The sampling date, nested in farm unit, and the pen type were considered as random effects. Although different pens could belong to the same farm, differences might exist between the different visits over time or season and the changes that might occur over time are farm specific (Courboulay et al., 2009; Pandolfi et al., 2017). For the five models, the independent variables considered were the variables: pen size, ventilation type, weight of the pigs, feed availability, feed form and feeder type, enrichment. Data were dichotomised to give categories with and without substrates, objects, substrates+objects, or no enrichment for the multivariable analyses. For the model with the proportion of pigs with severe tail lesions, the variable pig weight was transformed as follows (pigs ≤ 50 kg, pigs > 50 kg) to solve a problem of quasi-complete separation. The influence of the variables tail docking and length of the tails were also assessed when the dependent variable was the proportion of pigs with severe tail lesions, the proportion of pigs with severe body marks, or enrichment use ratio. Similarly, the influence of enrichment use ratio was assessed when the dependent variable was the proportion of pigs with severe tail lesions or the proportion of pigs with severe body marks.

Univariate analyses were initially carried out. All of the dependent variables with $P < 0.1$ were retained for the multivariable analyses. Associations between dependent variables were identified in the previous descriptive analysis, suggesting that the individual contribution of each covariate is difficult to assess (Tu and Gilthorpe, 2012). In order to diagnose the potential problem of multicollinearity, the variance inflation factor (VIF) was calculated. Based on this result, the variables with VIF ≥ 5 were removed to create the final model (Rogerson, 2001). The variables in the final model with $P \leq 0.05$ were considered significant.

2.3.2. Multiple correspondence analysis

A multiple correspondence analysis (MCA) was conducted to analyse systematic patterns of variations of environmental characteristics in the pig farms and illustrate the relationship between these. The decomposition of the inertia on the two first factorial axes (F1 and F2), considered as the most discriminating, was used to eliminate the variables with a low absolute contribution. As no standard value has been strictly defined (Messad, 2012), we eliminated variables under a subjectively chosen limit of 500 units of total variance (5% of the total absolute contribution of 10 000 units of total variance). After this selection, the contributions of the variables to each factorial axis and the plot of MCA were used to interpret each factorial axis. In order to better understand the connection between the environment and farm practice and the welfare outcomes, the five welfare outcomes were transformed into categorical variables and considered as supplementary variables in the MCA. The position on the MCA graph of the welfare outcomes helped to interpret the association with environmental variables.

Moreover, in order to understand the relationship between the magnitude of prevalence of the four physical welfare outcomes and the environment, we dichotomized each welfare outcome several times based on different thresholds (absence of the outcome, outcome higher than mean, 0.5%, 1%, 5% and 10%) to create additional variables. Following a similar logic, the enrichment use ratio was also dichotomized based on different thresholds (0.75, 0.50, 0.20, 0.10). These increasing thresholds were arbitrarily chosen to assess if the position on the factorial axes changed. After the transformation, these 28 supplementary variables were plotted on the MCA graph for interpretation.

In order to confirm differences between welfare outcomes according to their position on the MCA graph, Mann-Whitney tests were used to compare the distribution of the five welfare outcomes for the samples of pens with negative coordinates and those with

Table 3
Results of a generalized linear mixed model of risk factors for lameness at pen-level including 112,240 pig pens, 2013–2016, UK.

variables	levels	Odds	95% CI		P values
substrates	no substrates	1.00			
	substrates	0.87	0.79	0.97	**0.012**
objects	no objects	1.00			
	objects	0.89	0.79	1.01	0.069
substrates+objects	no objects+substrates	1.00			
	objects+substrates	1.46	1.18	1.81	**<0.001**
ventilation type	natural ventilation	1.00			
	powered ventilation	1.05	0.93	1.19	0.431
weight	weight >50 kg	1.00			
	weight <30 kg	1.48	0.66	3.35	0.343
	weight 30–50 kg	0.80	0.69	0.92	**0.003**
feed form	meal	1.00			
	liquid	1.63	1.29	2.05	**<0.001**
	pellets	1.21	1.02	1.43	**0.027**
feed availability	ad libitum	1.00			
	restricted	1.13	0.92	1.38	0.238
pen size	large pens	1.00			
	small pens	2.05	1.81	2.32	**<0.001**
	medium pens	1.54	1.39	1.71	**<0.001**

positive coordinates on F1. Moreover, since the different variables representing lameness and pigs requiring hospitalization above different limits (0.5%, 1%, 5%, 10%) showed different positions on the MCA graph (moving from upper left to upper right quadrant) and the variables representing severe tail lesions and severe body marks remained on the lower right quadrant, Mann-Whitney tests were used to compare the distribution of lameness and pigs requiring hospitalization for the sample of pens with positions in the upper right quadrant (positive coordinates on F1 and positive coordinates on F2) with all the other pens, and to compare the distribution of severe tail lesions and severe body marks for the sample of pens with positions in the lower right quadrant (positive coordinates on F1 and negative coordinates on F2) with all the other pens.

Data processing was carried out using Microsoft Access Office Professional Plus 2010, Microsoft Excel Office Professional Plus 2010 and RStudio for R-3.1.0 software for Windows (64 bit) to create the dataset at pens level and perform the analyses

3. Results

3.1. Sample size

After adjusting the sample size by accounting for the design effect, the power of the analyses with an accepted margin of error of 10% of the real population mean was 72.2% for pigs requiring hospitalization,42.8% for lameness, 30.9% for severe tail lesions, 46.0% severe body marks and 100% for enrichment use ratio, and, with an accepted margin of error of 20% of the real population mean, was 99.9% for pigs requiring hospitalization, 94.5% for lameness, 83.2% for severe tail lesions, 96.1% severe body marks and 100% for enrichment use ratio. The values of σ, e, ICC, m, N and Deff for each welfare outcome can be found in Table S1 in the supplementary file.

3.2. Influence of the environment on the welfare outcomes

Extensive descriptive results have been presented in a previous publication (Pandolfi et al., 2017). At pen level, the mean and standard deviation of prevalence of pigs requiring hospitalization was 0.07 (±0.26), the prevalence of lame pigs was 0.18 (±0.60), the prevalence of severe tail lesions was 0.14 (±0.69), the prevalence of severe body marks was 0.26 (±1.11) and the mean enrichment ratio was 0.50 (±0.27). The median and the 10–90% percentiles were all equal to zero for prevalence of pigs requiring hospitalization, lameness, severe tail lesions and severe body marks and, for the enrichment use ratio, were equal to 0.51, 0 and 1 respectively.

3.2.1. Lameness

The mean prevalence of lameness was 0.20 (±1.28) in indoor pens, 0.39 (±1.40) in outdoor pens, 0.30 (±1.45) in in&outdoor pens and 0.23 (±2.28) in other pens. The median and the 10–90% percentiles were all equal to zero for all pen types except for outdoor pens where the 90% percentile was equal to 1.1%. The Kruskall Wallis test showed that the mean prevalence was significantly lower in indoor pens compared to outdoor ($P < 0.01$) and in&outdoor pens ($P = 0.03$) and significantly higher in outdoor pens compared to in&outdoor pens ($P < 0.01$) and other pens ($P < 0.01$). All VIF were between 1 and 2. In the multivariable analysis, compared to the pigs fed on meal, the proportion of lame pigs was higher in pens fed on liquid feed ($P < 0.001$) and pellets ($P = 0.03$). The proportion of lame pigs was also higher in small ($P < 0.001$) and medium pens ($P < 0.001$) compared to large pens. Pigs that weighed between 30 and 50 kg had less lameness than pigs over 50 kg ($P = 0.003$). The proportion of lame pigs was also lower when substrates were present ($P = 0.012$) but was higher when substrates and objects were both present ($P < 0.001$) (Table 3).

3.2.2. Pigs requiring hospitalization

The mean prevalence of pigs requiring hospitalization was 0.08 (±0.79) in indoor pens, 0.07 (±0.44) in outdoor pens, 0.13 (±0.87) in in&outdoor pens and 0.09 (±0.66) in other pens. The median and the 10–90% percentiles were all equal to zero for all pen types. The Kruskall Wallis test showed that the mean prevalence was significantly lower in outdoor pens compared to in&outdoor pens ($P < 0.01$) and indoor pens ($P < 0.01$). The mean prevalence was significantly lower in indoor pens compared to in&outdoor pens ($P = 0.02$) and other pens ($P = 0.03$). All VIF were between 1.53 and 2.31. In the multivariable analysis, the proportion of pigs requiring hospitalization was higher when the pigs were fed with liquid feed ($P < 0.001$) or pellets ($P = 0.001$) compared to pigs fed with meal. This outcome was also more prevalent in pens with powered ventilation ($P = 0.01$) compared to natural ventilation, and in small ($P < 0.001$) and medium pens ($P < 0.001$) compared to large pens. The proportion of pigs requiring hospitalization also tended to be smaller when substrates were present ($P = 0.050$) (Table 4).

3.2.3. Severe tail lesions

The mean prevalence of severe tail lesions was 0.17 (±1.60) in indoor pens, 0.07 (±0.93) in outdoor pens, 0.22 (±1.85) in

Table 4
Results of a generalized linear mixed model of risk factors for pigs requiring hospitalization at pen-level including 112,240 pig pens, 2013–2016, UK.

variables	levels	Odds	95% CI		P values
substrates	no substrates	1.00			
	substrates	0.86	0.73	1.00	**0.050**
objects	no objects	1.00			
	objects	0.88	0.75	1.08	0.133
ventilation type	natural ventilation	1.00			
	powered ventilation	1.25	1.06	1.48	**0.010**
pen size	large pens	1.00			
	small pens	2.62	2.18	3.15	**<0.001**
	medium pens	1.89	1.61	2.23	**<0.001**
feed form	meal	1.00			
	liquid	1.58	1.21	2.06	**<0.001**
	pellets	1.38	1.13	1.68	**0.001**

Table 5
Results of a generalized linear mixed model of risk factors for severe tail lesions at pen-level including 112,240 pig pens, 2013–2016, UK.

variables	levels	Odds	95% CI		P values
substrates	no substrates	1.00			
	substrates	0.76	0.62	0.94	**0.012**
objects	no objects	1.00			
	Objects	0.88	0.70	1.11	0.275
substrates+objects	no objects+substrates	1.00			
	objects+substrates	2.16	1.53	3.06	**<0.001**
ventilation type	natural ventilation	1.00			
	powered ventilation	1.09	0.92	1.29	0.321
pen size	large pens	1.00			
	small pens	1.24	1.01	1.52	**0.042**
	medium pens	1.40	1.17	1.68	**<0.001**
weight	weight ≤50 kg	1.00			
	weight >50 kg	1.39	1.12	1.74	**0.004**
feed form	Meal	1.00			
	Liquid	1.48	1.05	2.10	**0.026**
	Pellets	1.50	1.14	1.97	**0.003**
tail length	tail lengths ≤ 0.5	1.00			
	tail lengths >0.5	0.82	0.68	1.00	**0.046**

in&outdoor pens and 0.22 (±1.27) in other pens. The median and the 10–90% percentiles were all equal to zero for all pen types. The Kruskall Wallis test showed mean prevalence was significantly lower in outdoor pens compared to indoor (P = 0.05), in&outdoor pens (P < 0.01) and other pens (P < 0.01). All VIF were between 1.01 and 2.79 except feeder type, which had VIF > 5 and was removed from the final model. In the multivariable analysis, the proportion of severe tail lesions was higher when the pigs were fed with liquid feed (P = 0.026) or pellets (P = 0.003) compared to pigs fed with meal. The proportion of pigs with severe tail lesions was higher in small pens (P = 0.042) and medium size pens (P < 0.001) compared to large pens. The proportion of pigs with severe tail lesions was also more prevalent for pigs with a weight over 50 kg compared to those under 50 kg (P = 0.004). The proportion of pigs with severe tail lesions was lower when substrates were present (P = 0.012), but was higher when substrates and objects were both present (P < 0.001). Finally, severe tail lesions were less prevalent in pens with pigs with tail longer than half of the undocked size (P = 0.046) (Table 5).

3.2.4. *Severe body marks*

The mean prevalence of severe body marks was 0.29 (±1.96) in indoor pens, 0.12 (±0.84) in outdoor pens, 0.33 (±2.05) in in&outdoor pens and 0.24 (±1.43) in other pens. The median and the 10–90% percentiles were all equal to zero for all pen types. The Kruskall Wallis test showed mean prevalence was significantly lower in outdoor pens compared to in&outdoor pens (P = 0.05). All VIF were between 1 and 1.23. In the multivariable analysis, the proportion of pigs with severe body marks was lower in pens with restricted feed (P < 0.001) compared to ad libitum feed but higher in pens with powered ventilation (P < 0.001) compared to natural ventilation. This outcome was also more prevalent for pens of pigs with a weight between 30 and 50 kg (P < 0.001) compared to those over 50 kg. The proportion of pigs with severe body lesions was lower for pigs with tails longer than half of the original length (P = 0.046) (Table 6).

3.2.5. *Enrichment use ratio*

The mean ratio was 0.47 (±0.36) in indoor pens, 0.67 (±0.35) in outdoor pens, 0.40 (±0.39) in in&outdoor pens and 0.37 (±0.32) in other pens. The median and the 10–90% percentiles were equal respectively to 0.5, 0 and 1 for indoor pens, 0.76, 0 and 1 for outdoor pens, 0.33, 0 and 1 for in&outdoor pens and 0.33, 0 and 0.88 for other pens. The Kruskall Wallis test showed mean ratio was significantly lower in indoor pens, in&outdoor pens and other pens compared to outdoor (P < 0.001). The mean ratio was significantly higher in indoor pens compared to in&outdoor pens (P < 0.001). All VIF were between 1 and 2.08. In the multivariable analysis, the enrichment use ratio tended to be lower in pens fed with liquid feed (P = 0.046) compared to the pens fed with meal. The enrichment use ratio was lower in pens with powered ventilation compared to natural ventilation (P < 0.001), in small (P < 0.001) and medium pens (P < 0.001) compared to large pens. The pigs that weighed between 30 and 50 kg showed more relative interaction with the enrichment than the pigs over 50 kg (P < 0.001).The proportion of pigs that interacted with enrichment instead of other pigs or pen fittings was higher when substrates were present in the pen (P < 0.001) and when the tails of the pigs were not docked (P = 0.017) (Table 7).

3.3. *Multiple correspondence analysis*

After a first decomposition of the inertia, the variables related to some pen types, some enrichments, ventilation type, feed type, feed availability, feeder type, tail docking, and tail lengths were

Table 6
Results of a generalized linear mixed model of risk factors for severe body marks at pen-level including 112,240 pig pens, 2013–2016, UK.

variables	levels	Odds	95% CI		P values
objects	no objects	1.00			
	Objects	1.10	0.97	1.24	0.128
ventilation type	natural ventilation	1.00			
	powered ventilation	1.51	1.33	1.73	**<0.001**
weight	weight >50 kg	1.00			
	weight <30 kg	0.73	0.25	2.15	0.566
	weight 30–50 kg	1.45	1.20	1.75	**<0.001**
feed availability	ad libitum	1.00			
	restricted	0.55	0.40	0.75	**<0.001**
tail docking	docked tails	1.00			
	undocked tails	0.90	0.67	1.20	0.460
tail length	tail lengths ≤0.5	1.00			
	tail lengths >0.5	0.83	0.68	1.00	**0.046**

Table 7
Results of a generalized linear mixed model of risk factors for enrichment use ratio at pen-level including 112,240 pig pens, 2013–2016, UK.

variables	levels	Odds	CI 95%		P values
substrates	no substrates	1.00			
	substrates	1.187	1.086	1.299	**<0.001**
objects	no objects	1.00			
	objects	0.92	0.84	1.01	0.093
ventilation type	natural ventilation	1.00			
	powered ventilation	0.74	0.65	0.84	**<0.001**
pen size	large pens	1.00			
	small pens	0.65	0.59	0.73	**<0.001**
	medium pens	0.81	0.74	0.88	**<0.001**
weight	weight >50 kg	1.00			
	weight <30 kg	1.37	0.73	2.59	0.332
	weight 30–50 kg	1.33	1.17	1.51	**<0.001**
feed form	meal	1.00			
	liquid	0.78	0.62	0.99	**0.045**
	pellets	0.99	0.83	1.19	0.945
feed availability	ad libitum	1.00			
	restricted	0.92	0.75	1.13	0.448
tail docking	docked tails	1.00			
	undocked tails	1.22	1.04	1.43	**0.017**

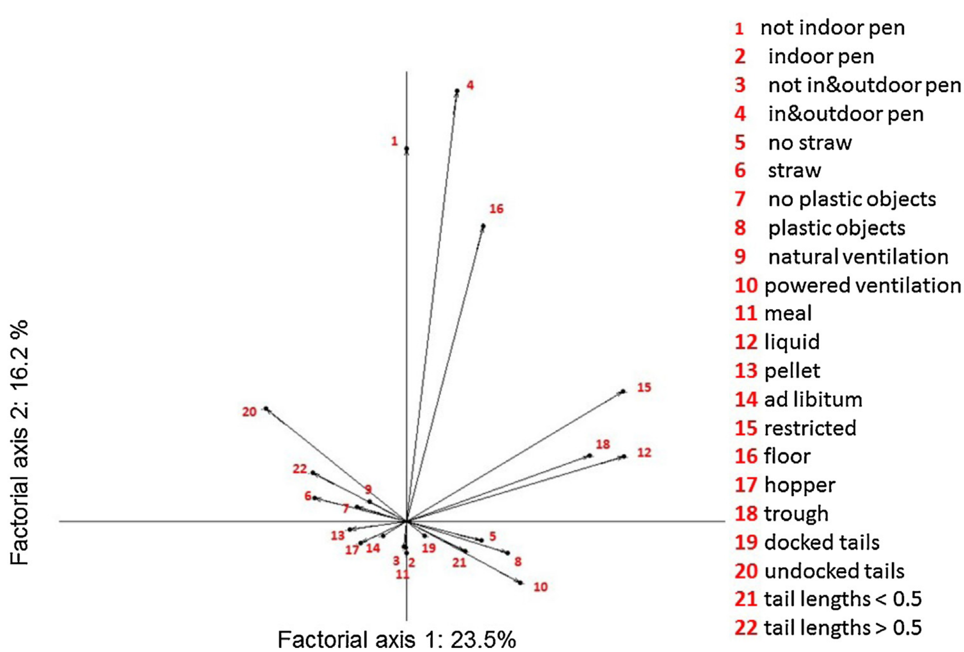

Fig. 1. Graphical solution of the Multiple Correspondence Analysis (MCA) on the first and second factorial axis for production characteristics of 112,240 pens of finishing pigs sampled on UK farms from 2013 to 2016 using the "Real Welfare" assessment protocol. Each variable is plotted on the graph according to the coordinates on factorial axes F1 (horizontal) and F2 (vertical), which explained respectively 23.5% and 16.2% of the total inertia of the 22 variables.

selected for the analysis (because inertia > 500) and transformed into dichotomized variables for the analysis (Table S3 supplementary file). The two first factorial axes, which explain the larger amount of variance of all variables used to run the MCA, were used to interpret the pattern of relationships of several categorical variables related to the environment and to simplify the interpretation by reducing the dimensionality of the data. The two first factorial axes represented in this analysis 39.6% of the total inertia (total variance of all variables included in the analysis). The first factorial axis (F1), which explained 23.5% of variance, appeared to differentiate less intensive, straw-based accommodation from controlled environment systems, while the second axis (F2), which explained 16.2% of variance, appeared to differentiate systems with an outdoor component from indoor systems and (Table S2 supplementary file). The absolute contributions are reported in Table S3 of the supplementary file. Fig. 1 shows the patterns of farm characteristics. The MCA revealed that certain categories of the variables considered seem to be connected (appearing close to each other and in the same direction on the graph). The use of liquid feed was related to restricted feed and distribution of the feed in a trough. The feed distributed on the floor was related to in&outdoor pens. Having short-tail pigs was related to the presence of plastic objects, pens without straw and powered ventilation. Having pigs with undocked or long tails was related to the presence of straw, the absence of plastic objects and natural ventilation. Undocked pigs, pens with straw and natural ventilation and feeding with meal or pellets had negative coordinates on the horizontal axis (F1) while pens with powered ventilated systems, liquid feed, without straw, with tail docked pigs and plastic objects for enrichment had positive coordinates on the horizontal axis (F1).

The variables representing the welfares outcomes were plotted on the MCA graph as supplementary variables. The presence, or a prevalence higher than the mean, for lameness and pigs requiring hospitalization were represented close to each other and to the variables “no plastic objects” and “natural ventilation”. The presence, or a prevalence higher than the mean, for severe tail lesions and body marks were represented close to each other and close to the variable “tail docked” and in the same direction as “tail lengths <0.5” and “no straw” (Fig. S1, S2 supplementary file).

Fig. 2 shows that the coordinates of the variables representing a percentage of lameness or pigs requiring hospitalization higher than 0.5%, 1%, 5% and 10% shift progressively from the negative to the positive side of the factorial axis F1. The variables representing the enrichment use ratio below the different limits tended to have positive coordinates on the factorial axis F1 (Fig. S3 supplementary file). This observation suggests different associations with the environmental variables according to the magnitude of lameness and pigs requiring hospitalization within a pen. Although lower percentage values were still close to each other and to the variable “no plastic objects” and “natural ventilation”, the variables representing higher incidences (1, 5 and 10%) and low enrichment use ratio were located in the same direction as liquid feed, trough feeder, floor feeding, restricted feed and in&outdoor pens. The variables “severe body marks >10%” and “severe tail lesions >10%” were still close to “no straw” and “docked tail pigs” and remained in a similar position to the lower percentages (Fig. 2).

The results of Mann-Whitney tests showed that the distribution of the sample of pens with negative coordinates and those with positive coordinates on F1 was different for pig requiring hospitalization, lameness, severe body marks and enrichment use ratio ($P < 0.05$) but not for severe tail lesions. Furthermore, results of Mann-Whitney tests showed that the distribution of the samples of pens with positive coordinates on F1 and positive coordinates on F2 and the sample of all the other farms was different for lameness ($P < 0.05$) but not for pigs requiring hospitalization. The distribution of the samples of pens with positive coordinates on F1 and negative coordinates on F2 and the sample of all the other farms was different for severe tail lesions and severe body marks ($P < 0.05$).

4. Discussion

The objective of the study was to identify risk and protective factors for five main welfare indicators collected on UK pig farms. The large sample size and the longitudinal nature of the data provided a good representativeness of commercial pig farms in the UK; as highlighted Mullan et al. (2009), a satisfactory estimation of the low prevalence of the welfare outcomes can only be achieved with very large sample size.

4.1. Sampling and limitations

Our choice to conduct the analysis at pen level was supported by the results of Taylor et al. (2012), who found no differences in tail biting between systems at farm level but some differences for descriptors at pen level. The analysis showed that good power could be achieved when a margin of error of maximum 20% from the real population mean for the different welfare outcomes was accepted. When a margin of error of maximum 10% from the real population mean for the different welfare outcomes was accepted, the power of the analysis was more limited, especially for lameness, severe body marks and severe tail lesions. In multivariable analysis, the P-value assesses the strength of the associations between the dependent variables and the potential risk factors. As the P-value reflects both the size of the sample and the magnitude of the effect (Blumenthal et al., 2001), nationwide collection of large datasets is more effective to reduce potential bias. Although several different assessors collected the data, information bias was thought to be limited as they all received the same formal training. Several studies have shown good inter-observer reliability of similar welfare outcome data recorded by trained assessors (Main et al., 2000; Mullan et al., 2011).

The sampling was organized to select, as randomly as possible, pens and pigs representative of the farms. Although it is possible that selection bias might have occurred in the first stage, since only Assurance Scheme members were represented, Red Tractor members represent more than 90% of the pig farmers in England. We used a model that controlled for unknown confounding factors connected to farm, time and pen type and the multivariable analysis also permitted us to produce odds ratios adjusted for the other covariates in the model. To account for the many correlations between variables, we calculated the VIF associated with their inclusion. While a VIF < 5 is considered as acceptable (Rogerson et al., 2001), the inclusion of variables with a VIF between 1 and 5 might led to some misinterpretations for unrepresentative samples (Vatcheva et al., 2016); however, the large sample and the combined MCA allowed a better interpretation of the results. As the main objective was to understand the influence of the environment on the welfare outcomes, and not only the inter-connections between welfare outcomes, we used a MCA adapted to qualitative data with the environmental variables as active variables and the welfare outcomes as supplementary variables.

It must be highlighted that the assessments relate only to pens in the mainstream herd, with the exclusion of hospital pens. This is likely to reduce the estimate of the total prevalence of problems at farm level, since with good management any seriously sick/injured pigs would be moved to hospital pens. Therefore, our assessment was of the association of different variables with a reduction of detrimental welfare outcomes in the mainstream herd, as a consequence of either a general improvement of welfare in the whole farm or better management of sick animals and hospital pens.

4.2. Associations between variables

The association between variables, and the potential confounding effects arising from this, have been highlighted in

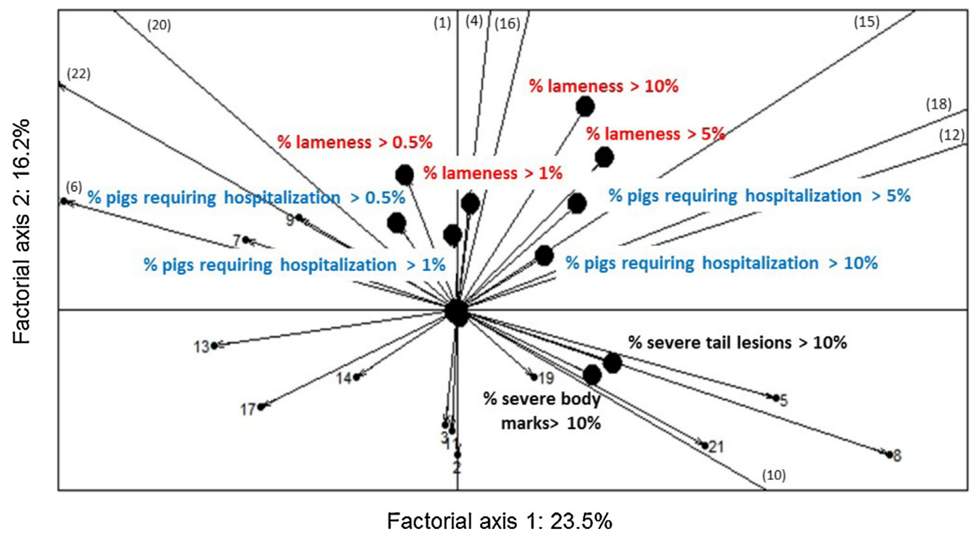

Fig. 2. Partial representation of Fig. 1 plot, based on 112,240 pens of finishing pigs sampled on UK farms from 2013 to 2016 using the "Real Welfare" assessment protocol, with the addition of the supplementary variables related to different prevalences of lameness, pigs requiring hospitalization, tail lesions and body marks on the first and second factorial axis of the MCA graph, along with the active variables and the axes connecting the variables (number in brackets on the MCA graph): not indoor pen (1), indoor pen (2), not in&outdoor pen (3), in&outdoor pen (4), no straw (5), straw (6), no plastic objects (7), plastic objects (8), natural ventilation (9), powered ventilation (10), meal feeding (11), liquid feed (12), pellets feeding (13), feed always available (ad libitum) (14), restricted feed (15), floor feeding (16), hopper feeding (17), trough feeding (18), docked tails (19), undocked tails (20), tail lengths <0.5 (21) and tail lengths >0.5 (22).

previous studies (Munsterhjelm et al., 2015a). In this study, at least two sets of interconnected variables were apparent. One set represented variables more connected to conventional systems (restricted liquid feeding in troughs, and unbedded, controlled-environment systems with object enrichment), while the other set were connected to farms that have implemented supplementary "welfare-friendly" initiatives (straw, undocked tails). Moreover, the different welfare outcome measures did not all co-locate on the MCA plot; a connection appeared between lameness and pigs requiring hospitalization, which differed from severe body marks and severe tail lesions that were located in the opposite quadrant. Lameness and pigs requiring hospitalization had been previously found to be associated in this dataset (Pandolfi et al., 2017), but results contrast with those of Munsterhjelm et al. (2015b), who also excluded hospital pens from their analysis and found a connection between wounds and lameness.

4.3. Pen type and farming system

As suggested by Barton Gade (2002), both intensive and more extensive systems present advantages and disadvantages. In the current study, only the prevalence of lameness tended to be higher outdoors, and this was higher also in in&outdoor compared to indoor pens. The prevalence of pigs requiring hospitalization, severe tail biting damage and severe body marks were lower in outdoor pens and the highest prevalence was observed in in&outdoor pens. Contrary to our study, higher prevalence of tail biting, skin lesions and other health issues in abattoir data were identified in pigs from organic/free range systems in Danish herds (Kongsted and Sørensen, 2017; Alban et al., 2015), but the studies referred to all lesions, not specifically the severe ones, and only compared the system without considering other environmental parameters. Moreover, Walker and Bilkei (2006) showed that outdoor pens do not completely prevent tail biting, but pigs more frequently presented moderate wounds with low grade infection. According to the review of Schroder-Petersen and Simonsen (2001), indoor and outdoor temperatures both influence tail biting, such that the combination of variability in both might further increase risk; this suggests that the greater problems seen in in&outdoor pens may relate to control of the thermal environment experienced by the animal.

As reported D'Eath et al. (2014), welfare issues such as tail biting do not have a single cause; making the comparison between systems too simplistic. The MCA helped to clarify the complexity of the association between welfare outcomes and the environment. While the lower prevalence of lameness and pigs requiring hospitalization showed a certain degree of connection with "welfare friendly pens", the higher prevalence (above 1, 5 or 10%) was connected to in&outdoor pens, but also to liquid feed and restricted feed in troughs or on the floor. Thus, while a low prevalence of lameness or foot lesions can be expected with outdoor soil (KilBride et al., 2009a; KilBride et al., 2009b), the prevalence of welfare outcomes may not be only connected to a specific housing system. The complex interaction between welfare issues and the different variables might reveal endemic problems which constantly expose the animal to several inappropriate features in the environment.

The possible confounding effect between pen types and unrecorded risk factors such as health status, previous rearing environment and other management practices (Schroder-Petersen and Simonsen, 2001; Taylor et al., 2012; D'Eath et al., 2014), dampness and dirtiness (Geers et al., 1990; Von Borell and Van denWeghe, 1998; Smulders et al., 2006; Van De Weerd and Day, 2009), and floor type (Gentry et al., 2002; Straw, 2006; KilBride et al., 2009a) should be further explored. For example, pigs requiring hospitalization and with severe body marks were found more commonly in pens with powered ventilation. Draughts resulting in changed level of activity and dirtiness, high concentrations of dust and irritant gases or inadequate temperature are several risk factors that might be associated to powered ventilation of poor quality and affect pig health or welfare (Defra, 2003; Taylor et al., 2012; D'Eath et al., 2014; Michiels et al., 2015). Furthermore, although large pens were associated with lower prevalence of lameness, for pigs requiring hospitalization and with severe tail lesions, the pen size variable might indirectly measure the impact of space allowance, as bigger functional area per pig might be expected in larger pens and has been associated to a decrease of tail lesions (Munsterhjelm et al., 2015a). Moreover, an experimental study showed no differences in lameness with different pen size alone (Vermeer et al., 2014), suggesting that the increase of welfare outcomes is not only connected to the pen size but to several parameters in the environment. One study found that farmers with larger herds had better knowledge about hospital pen requirement (Thomsen et al., 2016). Farmer perception regarding pig sickness and requirement for hospitalization is likely to differ between individuals. The perception of hospitalization need may also be confounded with production circumstances and the degree of physical, thermal and social challenge provided by the home pen.

4.4. Feed

Similarly to previous studies (Van De Weerd and Day, 2009; Temple et al., 2012), pens with pigs fed with meal had lower prevalence of lameness, pigs requiring hospitalization and severe tail lesions in comparison with pigs fed liquid feed or pellets. The association of pelleted feed (Hunter et al., 2001) and liquid feeding (Temple et al., 2012) with an increase of tail biting has been reported in previous studies and might be explained by a better gut health with meal feeding (Taylor et al., 2010). Substrate, meal feed and large pens were associated in our previous study (Pandolfi et al., 2017), supporting the multifactorial aspect of welfare issues.

4.5. Enrichment and tail docking

Pens with substrates had a lower prevalence of lameness, pigs requiring hospitalization and severe tail lesions, consistent with previous studies (Courboulay et al., 2009; Van De Weerd and Day, 2009; Temple et al., 2012; Munsterhjelm et al., 2015a). However, enrichment type was not associated with severe body marks, as previously suggested by other studies (Van De Weerd et al., 2006; Temple et al., 2012). Although provision of substrates showed a positive impact on most welfare outcomes, objects were not associated with a positive effect but very few pens had no reported enrichment against which they could be compared. Many studies have suggested that substrates are more used by pigs and thus more effective to reduce inappropriate behaviors towards pen mates, compared to different objects (Bracke et al., 2006; Van De Weerd et al., 2006; Van De Weerd and Day, 2009; Scott et al., 2007, 2009). However, enrichment with wooden objects or hanging toys has shown positive impact in some studies (Scott et al., 2009; Cornale et al., 2015). Furthermore, straw-bedded and conventional systems have shown similarity in animal based measures in some studies (Guy et al., 2002; Taylor et al., 2012; Temple et al., 2012), suggesting that the substrate alone might not always be able to solve welfare issues. Surprisingly, an increase in lameness and severe tail lesions, which previous studies have indicated can be inter-related through infection (Niemi et al., 2012; Munsterhjelm et al., 2015b), were associated with the presence of objects combined with substrates. This raises the question about the confounding effect of substrates associated to objects, as multiple enrichments might have been used post hoc to control problems such as tail biting arising from other environmental and management issues (Niemi et al., 2012; Munsterhjelm et al., 2015b).

Substrate provision tended to be associated with a decrease of severe tail lesions and farms with this system are less likely to dock tails. The causality of the link between tail docking/tail length and tail biting cannot be inferred, since farms choosing not to dock tails, or to dock to a longer length, are likely to be those which have previously experienced little tail biting and therefore may be considered to have low-risk systems. However, the MCA indicated a certain degree of connection between docked tails, tail lengths under 0.5, absence of straw and higher prevalence of severe tail lesions and body marks. This confirms conclusions from the earlier study of Moinard et al. (2003) and more recent review of D'Eath et al. (2014) which suggested that tail docking, which is used to reduce tail biting risk, may not be totally effective on its own.

4.6. Practical recommendations

Our study identified differences between pig ages and housing systems in the prevalence of different welfare outcomes and points towards areas where attention should be given by the veterinarian and the farmer to improve pig welfare. The results suggest that particular attention should be given to specific welfare issues at different times of the production period. The lower prevalence of lameness in younger pigs, consistent with a previous study (Temple et al., 2012), and the higher prevalence of tail biting in older pigs suggests a benefit overall in targeting pigs over 50 kg for farm welfare assessment. However, severe body marks were more prevalent in younger pigs, as suggested by Temple et al. (2012). This pig category is more likely to have been recently mixed during group formation and particular attention should be given regarding body marks after regrouping.

Outdoor pigs seemed to be more exposed to lameness and the detection of lame pigs should be a focal point in outdoor systems. This can be achieved by regularly inspecting pigs in outdoor systems to identify affected individuals, but also by identifying risk factors in the environment and removing these if possible. However, the outdoor system showed benefits in improving the other welfare outcomes. In&outdoor pens, smaller pens and powered ventilation systems tended to promote a higher prevalence of lameness, pigs requiring hospitalization and severe body marks suggesting that closer inspection of the pigs should be targeted in such environments. The requirement for pigs to be removed to hospital pens comes from avoidance of further damage, contagion or to remove the pigs from a competitive environment to protect their welfare (White, 2009). Therefore, in order to avoid welfare issues, quicker hospitalization or intervention should be considered in pens presenting higher risk.

While less flexibility for change might be expected regarding pen type or infrastructures, the feeding system and the use of substrates, and their consequences for pig behavior and health, should be discussed between farmer and veterinarian as potential solutions to reduce lameness, pigs requiring hospitalization or tail biting. Regular inspection of the herd in high risk environments should be given a priority and the whole environment should be reviewed to ensure that appropriate space and features are provided to fully meet the needs of the animals. The reduction in the prevalence of welfare outcomes in the mainstream herd since the implementation of the “Real Welfare” scheme (Pandolfi et al., 2017) points towards the value of the scheme in improving animal welfare in a variety of situations.

5. Conclusions

Pen type, ventilation system, pen size, enrichment and feed provision were all associated with an impact on welfare outcomes. While the provision of substrate showed a positive impact on several welfare outcomes, tail docking does not seem to be effective on its own to reduce tail biting prevalence. Veterinarians and farmers should give particular attention to pen environment and feeding system to improve animal welfare in all farming systems. This study highlights individual risk factors which can be considered to improve animal welfare, but also indicates the need to consider the environment as a whole because of potential factor combinations and confounds. The need for large samples to assess risk factors for welfare outcomes with low prevalence and high variability between pens and farms should encourage the collection of additional data in the future.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.prevetmed.2017.07.008.

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