Case control study on environmental, nutritional and enrichment-based risk factors for tail biting in long-tailed pigs

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Abstract

A case control study with a questionnaire was carried out to compare feeding practices, diet composition, environmental factors and management in 78 herds with or without a history of tail biting in undocked pigs in Finland. Tail biting was measured as the mean annual prevalence score of tail biting damage (TBD). Logistic regression parameters were calculated separately for piglet, grower, and finisher units. Risk factors for TBD found in the piglet unit were slatted floors, area of slats and increasing number of finisher pigs at that farm. In the grower unit slatted floors, area of slats, increasing number of finisher pigs at that farm, use of whey or wheat in the diet, and use of purchased compound feeds were associated with the risk for TBD. In the finisher unit, slatted floors, area of slats, increasing number of finisher pigs at the farm, absence of bedding, liquid feeding, several meals per day, specialized production type and group size of above nine pigs were found as risk factors for TBD. The nutritional risk factors seem to operate together with other risk factors, but with relatively low odds. The risk factors of undocked herds in this study seem to be similar to the risk factors from earlier studies of docked pigs. This study provides information which can be used to refine decision support tools for management of the potentially higher risk for tail biting among the long-tailed pigs, thus aiding compliance with EU law and increasing pig welfare.

Keywords

Animal welfare; Environment; Feeding; Pig; Risk factor; Tail biting

Introduction

Tail biting is a behaviour giving rise to serious animal welfare and economic problems in modern pig production. Many environmental, feed-related or animal based risk factors increase the likelihood of onset of tail biting (see review from Taylor *et al* 2010). From an ethological point of view, tail biting has been connected to redirection of normal foraging or exploration behaviour to other pigs´ tails (e.g. Schrøder-Petersen & Simonsen 2001). The absence of suitable foraging material – feed, bedding or enrichment - is shown to make pigs redirect their exploration behaviour from the ground to other pen items and pen mates (Averos *et al* 2010), behaviours that appear together with increased levels of tail biting behaviour (Day *et al* 2002). Solutions that satisfy pigs´ needs for exploration, rooting and foraging are preferred in order to decrease the tail biting risk, but are not always practical from a farmers´ point of view (D´Eath *et al* 2014).

Whilst there are many anecdotal reports of nutritional risk factors for tail biting, both quantitative and qualitative in nature, there has been little critical research on this subject in epidemiological studies. Results which associate tail wounds or tail biting behaviour to limited feeding space, feeding frequency, deficits in diet quality or quantity, form of the feed or dysfunction of the feeder system do exist (Fraser 1987; Fraser *et al* 1991; Beattie et al 2005; Botermans & Svendsen 2000; Hunter *et al* 2001; Schrøder-Petersen & Simonsen 2001; McIntyre & Edwards 2002; Moinard *et al* 2003; Holmgren & Lundeheim 2004; Hessel *et al* 2006; Smulders *et al* 2008; Taylor *et al* 2012; Temple *et al* 2012). In many cases these come from experimental studies and there is limited evidence of their importance under practical farming conditions where multiple risk factors are present simultaneously, as remarked previously by Smulders *et al* (2008). The combined effect of environmental and nutritional limitations at farm level needs special attention in order to comprehensively measure the risk for tail biting.

Most of the epidemiological investigations are from short-tailed pigs as tail docking is widely carried out in the majority of European countries. There are few epidemiological studies or meta-analyses of the relationship between tail biting behaviour or tail damage and farm environment and feeding in long-tailed pigs. It is seldom mentioned, even in scientific papers, whether the pigs were tail-docked or not, but many studies are done in countries where docking is common. Only Holmgren & Lundeheim (2004) have used farms with long-tailed pigs as the sole source of an epidemiological study. Furthermore, Hunter *et al* (2001) and Moinard *et al* (2003) compared the risk of tail biting in??? docked and undocked pigs. In these studies it is likely that a variety of confounded factors influenced the risk of tailbiting and thereby whether or not farmers made the decision to dock or not. On the basis of these (these studies or one of them; which study is not clear based on the references) studies Moinard *et al* (2003) found that tail docking was positively associated with the magnitude of tail biting risk.

Since the European Union has a stated objective of encouraging countries to reduce tail docking (European Commission 2013), the need for knowledge of how to manage long-tailed pigs is growing. However, tail docking itself has negative implications for pig welfare through the experience of short and possibly longer term pain (Sutherland & Tucker 2011). Furthermore, tail docking does not guarantee pigs safety from tail biting. Since in Finland tail docking is forbidden, but pigs are mostly raised in a way similar to the majority of pig-raising in the EU contrary to countries who have a more restrictive legislation towards both the tail docking and pig welfare, Finland makes an interesting model country for studying risk factors for tail biting in long-tailed pigs.

This study aims at measuring the magnitude of tail biting damage risk caused by feeding practices, environmental predisposal (the feeding study) and diet composition (the diet study) concentrating on undocked pig populations in Finland. The study method is a case-control questionnaire between herds with or without a history of tail biting using odds ratios to measure the magnitude of the risk. Based on the ethological motivational background of tail biting, it is hypothesised that the risk factors are identical to those in docked pig populations but that their magnitude might be elevated.

Material and methods

Study design and herds

This case control study and questionnaire investigated environmental and nutritional factors associated with tail biting on Finnish farms. Tail biting was diagnosed as the prevalence of pigs scored as having tail damage during farm inspections. The farms were selected from the Finish pig health register called Sikava (run by The Association for Animal Disease Prevention ETT ra, PL 221, 60101 SEINÄJOKI; www.sikava.fi), where in total of 1954 farms were included at the time of the study. Sikava requires quarterly veterinary health care visits to estimate the frequency of tail biting damage (TBD) at the time of the visit, though some farms were visited more than and some less than four times a year. TBD was originally recorded using a 5 point scale describing the amount of TBD: 0= data missing, 1=none, 2= some TBD (1-5% of the pigs), 3= plenty (6-19% of the pigs) and 4= lots (over 20% of the pigs). TBD was estimated using only one estimate covering all the units and, therefore, all the pigs at farm (independent of the age of the pigs), so there was no possibility to know the prevalence of TBD within different units (piglet, grower or finisher unit). In this study we used TBD data which was gathered over two separate 12 month periods – year one (Y1) and year two (Y2) – with each farm included in only one year. This yearly period for Y1 was from 1.5.2008 until 30.4.2009 and for Y2 it was from 1.10.2009 to 30.9.2010. Farms with TBD recordings of all or single values of 0 were excluded from the data analysis. A TBD mean was calculated for every farm as the average of the yearly evaluations. TBD mean ± standard deviation of all farms was 1.84 ± 0.49 in Y1 (n=1954 farms) and 1.82 ± 0.48 in Y2 (n=1801 farms). The median of all observations was 2.00 within both studies (Figure 1).

TBD status for farms was used to designate them as either case or control farm. Case farms had a TBD mean value of >2.6 or >2.1 in Y1 and Y2, respectively. Reason for changing the lower TBD limit for a case farm status from 2.6 into 2.1 was because there were not enough farms having a TBD mean above 2.6 in Y2. In control farms no TBD was observed at the time of inspections and therefore they all had TBD mean of 1.0 (limits for TBD status shown in figure 1).

Invitation of herds for the feeding study

All together 289 case farms and 326 control farms within the Finnish Sikava-records fulfilled the above mentioned criteria and were invited to participate in the feeding study by letter. In Y1, a first reminder was given by letter and a second one by phone. No reminders were used in Y2 because in Y2 the purpose was not to achieve any specific number of farms but to increase overall sample size for Y1. Apart from the reminders, the methods of the study and the questionnaire used were the same in both the years. Each farm was invited only once in the study, even if it fulfilled the criteria for both years.

Invitation of herds for the diet study

All invitations for the diet study were sent in year 2011. This happened at the same time as Y2 farms were asked to join the feeding study. Those farms that had already participated the feeding study in Y1 were asked to supplement their participations with the diet questionnaire in the internet at this point. The invitations were sent by letter, and no reminders were sent. The total amount of farms invited to the diet study was 350 from Y2 farms and 49 from Y1 farms, from which 210 were case farms and 189 control farms.

Data collection

Feeding study

An internet-based questionnaire (QuestBack™) was used to collect the data unless the farm asked for an identical paper version. Seven farms were given the possibility to complete a pilot version of the questionnaire, after which final modifications were made for the main study. Questions were divided into the following categories: general questions (farm-related), environmental questions, feeding-related questions (feeds and feeding technique), questions about enrichments, and other questions; these category classes were not shown to the respondents. All questions were asked separately for piglet unit (pigs from birth to weaning, approx.. 0-10 kg), grower unit (pigs after weaning but before finishing, approx. 10-25 kg) and finisher unit (pigs from approx. 25 kg to slaughter), based on the farmers' answers to questions regarding the type of production that they had, and this was clearly pointed out to the respondents. A complete list of the questions is shown in supplementary material 1. There were primary category questions that every farm answered. In addition, there were detailed sub category questions that were visible or invisible, depending on the farmers´ answers to the primary questions. Where the sample size was insufficient for meaningful interpretation (power), these sub category questions were not further analysed. Tail biting status was evaluated through the questionnaire in order to compare the farmer´s opinion about the state of their farm to the data obtained through the official

Sikava-recordings. Farms with major health problems would have been removed from the study, but there were none.

Diet study

In the diet study the questions were asked as a part of the internet-based questionnaire used in the feeding study for Y2 farms or a separate paper version for Y1 farms, both at the same time (in year 2011). Within the diet study we asked for information regarding whether the farm used the following products, with questions asked separately for piglet, grower and finisher units: barley, oats, wheat, rye, maize, other grains, soybean, rape or turnip rape, peas, barley protein concentrate, whey (wet or dry), protein concentrate, limestone, phosphate, salt (*NaCl*), mineral mixture, vitamin mixture, amino acid mixture, or purchased compound feed (PCF). For PCF, we asked questions allowing us to identify the manufacturer, name of the product and production period. The recipes for PCF were provided by feed manufacturers (Hankkija Agriculture Ltd, Raisioagro Ltd, A-rehu Oy). For all type of feeds (farms´ own mixture or PCF) statistical analyses were done using only the data of ingredients and not the accurate percentage of these in recipes.

Data management and statistical analysis

Within the feeding study, the total response rate was 19 % in Y1 and 12 % in Y2 giving a total of 90 farms. Within the diet study, the total response rate was 13 %. Reasons for exclusion of herds from the final dataset were changes in management and feeding practices (8 farms) during the time period data-recordings were collected. Four farms were removed for other reasons like inconsistency of their answers or answering twice. Furthermore, if the questionnaire was incorrectly completed, the farm´s answers for that particular production stage (piglet, grower or finisher stage) were removed from the study (N=2, 9, 9 stages, respectively), but the farm as whole was not excluded. The final data consisted of a total of 78 farms from which farms included in the diet study are a subset (n=50). Within the feeding study, 46 farms raised piglets (15 cases, 31 controls), 39 raised growers (14 cases, 25 controls) and 61 raised finishers (36 cases, 25 controls). Within the diet study, 24 farms raised piglets (9 cases, 15 controls), 29 raised growers (10 cases, 19 controls) and 44 raised finishers (24 cases, 20 controls).

Sample size calculations were done beforehand (only the feeding study) and again afterwards (both the studies). Intended power was 80% and confidence of 95 %. After completing data collection and excluding farms according to criteria listed above the ratio between case and control farms was 1:1 as intended beforehand within both the studies.

Explanatory variables (questions) were first analysed against TBD (case-control) - status using cross tabulation to determine if enough observations in each class were obtained and to identify the reference category. Answer choices within a question were combined into new groups if this was needed in order to obtain enough observations within cells and if appropriate. Only the final combined categories for each variable are presented within the results. Pearson chi-square was used for categorical variables with only two levels, the likelihood ratio chi-square test for variables with more than two levels and one-way Anova for continuous variables. After this, univariate logistic regression was applied to obtain unadjusted odds ratios (OR) and 95 % confidence intervals (CI) for those variables significantly associated with TBD status ($P < 0.05$). Logistic regression parameters were calculated separately for piglet, grower, and finisher phases. The model fit was tested using the hit ratio (% of observations estimated correctly) and the model coefficient of determination by Cox & Snell´s R^2.

All significant variables' multicollinearity and the type of association was tested using stratified bivariate cross tabulation with status as outcome variable. Furthermore, the number of finisher pigs at farm was tested for associations with all other significant risk factors using one-way Anova. If there was no data given on number of animals at farm, imputation was made using the mean of all farms. Multivariate logistic regression could not be done, because factors with multicollinearity were equal regarding their biological relevance but might not have mirrored the same biological mechanism, so no variable could be excluded from the model before another one without at the same time increasing the risk for incorrect choice.

SPSS 18.0 was used for all statistical analyses excluding sample size estimates and detailed variable multicollinearity. Variable interaction and confounding were tested with Epi Info 7.1.0.6 (Centers for

Disease Control and Prevention 2012) using StatCalc and 2 x 2 tables programs, and with PS – Power and Sample Size Calculation (Dupont & Plummer 1990).

Results

Feeding study

General information about farms is given in table I. In this table the information about tail biting at the farm is the farmer´s opinion of the situation. Table II shows the results of the univariate contingency of the variables found to have a significant association with TBD status of the farm (case or control). In all the units these risk factors were fully or partly slatted pen floor compared to solid floor (SF) and the area of slatted floor which was further divided into three categories (1 – 49 % or 50 – 100 % slats compared to solid floor, ASF), and the increasing number of finisher pigs at the farm. In addition, only in the finisher unit we found more than 10 pigs compared to at the most of 10 pigs in a pen (NP), use of liquid feeding compared to dry feeding (LF), absence of bedding material compared to presence of it (BM), and type of production that had only finisher pigs compared to keeping the same pigs from birth to slaughter (TP) to be risk factors for TBD case status. There was no significant difference in TBD status when comparing “feeding in meals” and “feed present all the time” *per se*. However, after recoding the variables, feeding *ad libitum* (continuous) incurred an equal risk to one or two meals a day, resulting in “more than two meals offered a day compared to one or two meals or *ad libitum* feeding without separate meals” (NM) as a risk factor. In table III measures of the magnitude of the risk (odds ratios with confidence intervals), predictions of the model fit and model derived significances for each individual risk factor for piglet, for? weaner and finisher units from univariate logistic regression are presented.

The following variables (risk factors) were observed to have multicollinearity with each other in the presence of TBD status as the outcome variable: SF to LF, SF to BM, SF to NM, NM to LF, NM to BM, NM to TP, TP to NP, and TP to LF. These observed associations are shown in figures 2a-2h. We tested the nature of the association (whether the two variables were interacting or one was a confounding factor) using stratification. In addition, all units were separately associated with increased risk for TBD with increasing number of finisher pigs at the farm. However, it was impossible to use this variable as a covariate in univariate logistic regression models because the number of finisher pigs at the farms was found to be associated with SF (F=5.8, df=1, P<0.05), TP (F=14.7, df=1, P<0.001), LF (F=17.8, df=1, P<0.001) and NM (F=7.4, df=1, P<0.01). The following reported risk factor collinearities are from the finisher units. In the piglet and grower units, there were no further risk factor interactions to be examined.

In the finisher unit, having slatted floors increased the risk for TBD. Multicollinearity of SF to BM, NM and LF was found. After adjusting SF for BM, the risk of TBD associated with slatted flooring was reduced in farms using bedding (OR=6.5 CI 1,5 – 28.8; $\chi2$= 6,74; P<0.05; n=41) but was not evident in farms not using bedding (OR=8.0; CI 0.3 – 184.4; $\chi2$ = 2,14; P>0.1; n=20) compared to all farms having slatted floors (figure 2b). After adjusting SF to NM, farms with "1 or 2 meals or ad libitum feeding" tended to have lowered risk associated with SF (OR=4.4 CI 0.8 – 23.6; $\chi2$ = 3,24; P<0.1, n=27) in contrast to farms having "more than two meals" where OR increased (OR=9.2 CI 1.3 – 64.9; $\chi2$ = 6,05; P<0.05, n=34) compared to all farms having slatted floors (figure 2a). Furthermore, SF was found to be confounded with LF. In farms not having liquid feeding, the risk of TBD associated with SF was reduced (OR = 7,3 CI 1,5 – 36,7; $\chi2$ = 6,5; P < 0.05), but this effect (see previous comments) was not evident in farms not using liquid feeding (OR = 4,0 CI 0,45 – 35,8; $\chi2$ = 1,7; P > 0.1) compared to all farms having slatted floors (figure 2c).

Absence of bedding material in the finisher unit was associated with increased risk for TBD, although BM was confounded with SF. In farms with slatted floors, there was a decreased risk for TBD (OR =10,7 CI 1,21 – 93,7; $\chi2$ = 6,1; P < 0.05; n = 42) compared to all farms when BM was not used.. In finisher units with solid floors, there only tended to be an effect of not using bedding (OR = 8,7 CI0,58 – 130,1; $\chi2$ = 3,0; P < 0.1; n = 19) (figure 2b).

Number of meals (NM) had a significant effect on TBD in the finisher unit. *Ad libitum* feeding was described as "having free access to feeds all the time" and meal feeding as restricted feeding where "feed was not present all the time" even though the single meal size could have been calculated according to the appetite of the pigs. NM showed multicollinearity to LF, BM, TP and SF. After adjusting NM to LF, farms with liquid feeding tended to have increased risk for TBD if pigs were fed more than twice a day at the same time (OR = 8,4 CI 0,63 – 112,1; $\chi2$ = 3,3; P < 0.1; n = 29). There was no interaction effect in farms not having liquid feeding (OR = 1,4 CI 0,3 – 7,0; $\chi2$ = 0,17; P > 0.1; n=32) compared to all pigs being fed more than twice a day (figure 2d). When NM was adjusted to BM, in farms with absence of bedding material the association of NM to TBD could not be calculated because of a low number of observations (OR= undefined; $\chi2$ = 0,74; P>0.1; n=20) but in farms with presence of bedding material there was a protective effect of BM in "more than twice fed pigs" (OR = 4.6 CI 1.2 – 17.2; $\chi2$ = 5,33; P < 0.05; n=41) (figure 2h). When having all age of pigs at farm there was a tendency for lowering the risk of NM (OR = 3,5 CI 0,8 – 15,4; $\chi2$ = 0,86; P < 0.1; n = 34), but in farms having only finisher pigs there was no interaction with NM (OR = 2,3 CI 0,3 – 17,6; $\chi2$ = 0,63; P > 0.1; n = 27) (figure 2f). In farms with slatted floors the risk caused by feeding more than twice a day tended to be lowered (OR = 3,5 CI 0,8-14,5; $\chi2$ = 3,02; P < 0.1; n = 42) compared to all farms fed as described above. There was no interaction effect of solid floors on NM (OR = 1,7 CI 0,2 – 14,1; $\chi2$ = 0,22; P > 0.1; n = 19) (figure 2a).

Type of production (TP) was associated with TBD in the finisher unit. However, TP had an interaction with LF and NP. After adjusting TP to NP, when having "less than 10 pigs per pen" this risk of having only finisher pigs elevates compared to all group sizes (OR = 12.0 CI 1.2 – 117.4; $\chi2$ = 6,0; P < 0.05; n=31). In farms having "10 or more pigs per pen" there was no interaction with TP (OR = 0.6 CI 0.1 – 3.6; $\chi2$ = 0,34; P > 0.1; n=30) (figure 2g). Adjustment of TP to LF tended to increase the risk for TBD in finishing farms with no liquid feeding (OR= 4.4 IC 0.7 – 27.8; $\chi2$ = 2,79; P < 0.1; n=32) compared to all finishing farms. There was no interaction effect with finishing farms using liquid feeding (OR= 0.9 IC 0.1 – 5.6; $\chi2$ = 0,03; P>0.1; n=29) (figure 2e).

Use of liquid feeding in the finisher stage was significantly associated with TBD. LF had interaction with NM and TP. There tended to be increased risk for TBD in farms with liquid feeding and more than two feeding times (OR = 4.2 CI 0.8 – 22.9; $\chi2$ = 2,98; P < 0.1; n=34) compared to all liquid fed pigs. In farms having "1 or 2 meals or ad libitum feeding" we found no interaction with LF (OR = 0.7 CI 0.1 –

8.8; $\chi2$ = 0,08; P>0.1; n=27) (figure 2d). Within the interaction of LF and TP, having all age of pigs at a farm where finisher pigs were fed with liquid feed increased the risk for TBD (OR = 6.2 CI 1.1 – 36.6; $\chi2$ = 4,64; P<0.05; n=34) compared to all farms having liquid feeding. In farms having only finisher pigs there was no interaction with LF in the finisher unit (OR = 1.2 CI 0.2 – 8.2; $\chi2$ = 0,03; P>0.1; n=27) (figure 2e).

The number of pigs in one finisher pen (NP) was associated with the risk of TBD, when "less than ten pigs", "11-19 pigs" and "20 or more pigs" per pen were used as variable categories in the raw data (the questionnaire). The prevalence of having more than 20 pigs per pen turned out to be only five per cent. However, there was an interaction between NP and TP. The risk caused by larger group size (10 – 19) was higher in farms having pig of all age (OR = 8.0 CI 1.4 – 46.8; $\chi2$ = 6,17; P<0.05; n=34) compared to all production types. In farms with only finisher pigs there was no interaction effect on risk of NP (OR= 0.4 CI 0.0 – 4.0; $\chi2$ = 0,67; P>0.1; n=27) compared to all production types (figure 2g).

Diet study

No association was found in piglet and finisher units between TBD status of the farm (case or control) and use of different feed ingredients (P > 0.05). Within the grower unit we found use of purchased compound feed (PCF), whey and wheat to be associated with TBD status (in table IV). The use of whey and presence of liquid feeding was investigated because farms that have liquid feeding often use industrial by-products like wet whey as an ingredient of the liquid feed mixture, but there were only two farms having LF in the grower unit and neither of them used whey, so there was no confounding found. The interaction between use of PCF and use of whey or wheat in the grower unit seems likely, but this was impossible to test statistically due too low amount of farms divided according to use of PCF. In farms using PCF, 46 % and 93 % had whey or wheat in the grower diet, respectively. From those farms, whey was used in 4 out of 7 case farms and in 2 out of 6 control farms. Wheat was used in 7 out of 7 case farms and in 6 out of 7 control farms. The odds ratios of statistically significant diet related risk factors are reported in table V.

Discussion

In this study we used the Finnish pig health register “Sikava” to select case farms that had more than average tail biting damage, and control farms with no tail biting damage observed, and asked through an internet questionnaire about their farm management factors related to feeding, environment and diet choices for pigs of different age categories. The aim was to identify and quantify risk factors that might be the potential source of tail biting at these farms. We found environmental (slatted floors, the slatted area, absence of bedding, moderate to large group size), management based (type of production, number of finisher pigs at farm) and feeding related (liquid feeding, number of separate meals, use of whey or wheat or PCF for grower pigs) risk factors, mostly located to the finisher unit. The magnitude of the risk seemed to be higher within the first category (environment), but several interaction effects complicated interpretation of the findings.

Risk factors from the feeding study

Environmental risk factors

Slatted floors were found to be associated with increased risk for TBD within each production stage in this study. Completely solid floors were rare (7 – 20 %) within the case farms, whereas they were relatively common (52 – 77 %) within all the control farms in each production stage. Solid floors are shown to decrease time spent expressing social behaviours (Averos et al 2010). In weaned and finisher pigs, the risk associated with slatted floors also increased as the area of slats increased, although the confidence intervals of odds ratios for slatted areas were wide. Fully slatted floors were reported to increase tail biting in contrast to partly slatted floors by Ruiterkamp (1985) and Madsen (1980). In contrast, we found that in unweaned piglets, having 1-49 % slats in the pen area increased the risk for TBD more than having at least half slatted floors compared to solid floors in the piglet stage. This observation cannot be easily explained, but may result from only a few farms having a slatted area of more than 49 %. In contrasts to our results, Moinard *et al* (2003) found a significant difference only in the comparison between presence and absence of slats, not in the area of slats.

We found absence of bedding material in the finisher unit to be a risk for TBD, corresponding well to previous studies (Beattie *et al* 1995, Hunter *et al* 2001, Moinard *et al* 2003). Lack of bedding was marked as having the highest OR among finisher unit risk factors. In this study, “presence of bedding” was clarified in the questionnaire as “having bedding material put on the pen floor suitable to absorb the moisture; not only for enrichment or to play with”. None of the studies cited above, defined the amount of bedding provided to pigs. Even moderate bedding decreased the tail lesion index of undocked finisher pigs in the study of Munsterhjelm *et al* (2009), which is the amount of bedding used in most cases on Finnish farms. Besides, provision of moderate straw resulted in lower probability of TB than the provision of deep straw(Hunter *et al* 2001).

In the report from EFSA (2007), risk caused by slatted floors was not reported individually but in connection to use of straw, which might be of practical relevance. These kind of feeding and environment related relationships between multiple factors affecting tail biting behaviour are well described in the review by D´Eath *et al* (2014). In our study, there were many interaction effects between floor type, use of bedding material and management of feeding adjusting the odds of single risk factors for TBD. The risk associated with slatted floor structure increased in magnitude when pigs were fed more than twice a day. When pigs are fed in many separate small meals they might experience post-meal hunger resulting in increased expression of foraging behaviour. In an environment where the floor is slatted, there is usually a lack of sufficient amounts of chewing material on the floor fir pigs to fulfil their need to forage and explore, leading pigs to redirect their appetitive and exploratory behaviours from the ground to other animals (Averos *et al* 2010). This attentional shift increases the risk for two-stage tail biting behaviour (Taylor *et al* 2010). In addition, escalated competition at feeders (possibly multiple times a day), is a potential source of sudden-forceful tail biting (see Taylor *et al* 2010). In a situation where there is competition for feed, edible bedding materials as a source of non-nutritional fiber can also work as a buffer against digestive tract discomfort (Taylor *et al* 2010) and provide satiety for the pigs (Bolhuis *et al* 2010). This might explain the additive effect of the number of meals and slatted floors, and the protective effect of bedding in pens with slats, on the risk for TBD.

Moderate to large group size in pens was associated with increased risk of TBD, although in this study the majority of farms (95 per cent) reported having group size below twenty pigs (original data, not shown). Holmgren & Lundeheim (2004) who found that, an increase of one pig to the group increased the prevalence of tail biting by +0.2 % with long-tailed pigs, suggested that this was a consequence of an increase in the number of potential victim pigs. Crowding and large group size increases the exposure of one pig to other pig's bodies and tails (Fraser 1987, D´Eath *et al* 2014), and makes the copying of biting behaviour more likely (Fraser 1987). Furthermore, pathogens spread more rapidly with multiple animals close to one another, and tail biting has been shown to be associated with general suppressed health (Niemi *et al* 2011, Moinard *et al* 2003, Schrøder-Petersen & Simonsen 2001), and increased respiratory diseases (Moinard *et al* 2003; Sihvo *et al* 2012; Munsterhjelm *et al* 2013) and mortality (Moinard *et al* 2003). In contrast to our results, Schmolke *et al* (2003) found no effect of group size between ten or more pigs on TBD. The potential risk of large group size increasing tail biting behaviour is closely linked to limitations of feeder space and increased stocking density (Moinard *et al* 2003, D´Eath *et al* 2014). The first one (large group size) was not identified as a risk factor in this study and the second one (stocking density) was not investigated. However, 78 percent of finisher farms used feed troughs and the great majority of them (92 %) reported that finisher pigs were able to eat simultaneously for the whole growing period.

Feeding related risk factors

Although this study aimed at identifying potential feeding related risk factors using detailed questions about feeding technique, type of feed and manufacturing of the feed mixtures, only two feeding related risk factors were found: the use of liquid feed and offering more than two meals a day in the finisher unit. Feeding related risk factors were not found in the piglet or grower units.

Jericho and Church (1972) was the first to note that *ad libitum* feeding reduces tail biting. In this study meal feeding with more than two meals a day in the finisher unit was observed to increase risk for TBD. We suggest that our result might be a consequence of dividing the same amount of feed into several small portions, possibly resulting in pigs remaining hungry after a meal, as described earlier in this discussion. Increasing the number of meals has also been connected with growing competition at the feeder, antagonistic behaviour and increased skin lesions (Hessel *et al* 2006). Temple *et al* (2012) found time-restricted feeding systems to be associated more with severe wounds than *ad libitum* feeding systems. Furthermore, an increase in the frequency of feeding from two to four times a day induced larger relative risk for tail biting than feeding only once or twice a day (Temple *et al* 2012), which strengthens the conclusion that multiple, time-restricted feeding might increase the risk of tail biting in our study case farms.

Similar to our result, liquid feeding is recognized to predispose to tail biting in studies by Bracke *et al* (2004) and Temple *et al* (2012), although controversial results exist too (Hunter *et al* 2001; Moinard *et al* 2003; Smulders *et al* 2008). Liquid feeding might despite of its beneficial effects on growth, nutrient utilisation and gastrointestinal tract health (see Scholten *et al* 1999 for review) be a potential source of tail biting because synthetic amino acids may be degraded during storage of fermented feed (Pedersen *et al* 2002), and lack of protein or amino acids is associated with attraction to the taste of blood (Fraser *et al* 1991, McIntyre & Edwards 2002) and tail biting (Jericho & Church 1972). Diet nutrient content is also variavle with liquid feeding due to industrial by-products available which is known to induce tail biting behaviour (Fraser 1987). Managing the liquid feeding system requires more engineering skills from the farmer (de Lange *et al* 2006) than……. There is a source of error in managing the mixing process and delivering homogenous feed to all the pens in the building (de Lange *et al* 2006). The decreased dry matter content of feed provided in some pens can prevent satiety after a meal. Reduced satiety can increase restlessness and aggressive behaviour (Bolhuis *et al* 2010), which are behaviours also observed in tail biting pens (Zonderland *et al* 2011).

The risk for TBD caused by the use of liquid feeding tended to increase further when the daily ration of feed was divided into several small meals, and in addition the risk caused by having more than two meals tended to increase in liquid fed pigs. This is probably the result of the relationship between these two factors under practical farm conditions: liquid feeding is automated whereas dry feeding is mostly organized without any or only some automation (keeping in mind that the majority of farms had feed troughs, not one- or multi-space feeders). The number of working hours required by the farmer to feed by-hand is likely to limit the number of meals offered. Ninety percent of finisher farms using liquid feeding had more than two meals a day, whereas 75 percent of farms feeding the pigs with dry feeds had meals only once or twice a day or feed present at all times, which explains the additive effect of the risk factors observed within our data.

The risk connected to use of liquid feeding at the finisher stage (25 – 110 kg) was even more pronounced in farms having pigs from birth to slaughter, and when having only finisher pigs the risk was not significantly connected to TBD at all, than ... One reason for this interaction could be that piglets experience a change from dry feeding to liquid feeding at the time of the transition into the finisher unit. This was tested statistically, but there was no effect of the change in feed type on TBD (data not shown as non-significant). However, it is possible that the interaction and its effect on TBD was more affected by the size of the farm, total number of pigs, pigs per stockperson or number of units at farm than by type of production itself, as liquid feeding is more common in large farms. These were all recognized as risk factors for tail biting by Moinard *et al* (2003).

Management related risk factors

The total number of pigs per farm was connected to the risk for TBD. Increasing farm size by 100 finisher pigs was associated with a 0.4 % increase in odds of TBD. This means that farm size, even though being a significant risk factor for tail biting, has a relatively small practical influence. This is in accordance with Moinard *et al* (2003) who found a 1.01 fold increase in the risk for tail biting as the number of pigs slaughtered weekly increased by one. Increased number of pigs and pens per stockman is another risk factor for tail biting connected with larger farms (Moinard *et al* 2003).

Farms raising only finishers were associated with greater risk of TBD in the finisher unit compared to farms raising piglets from birth to slaughter. The reason for the higher risk in farms raising only finishers for TBD might be changing environment, feeding, human contact and social grouping when pigs are delivered from one farm to another according to their age – even three times in a lifespan. The pigs originating from the same farm (from birth to slaughter-production) might not experience stress associated with these changes. Pigs seem to be more vulnerable to tail biting behaviour if moved to another farm during the weaning-finishing period, as indicated by a greater proportion of truck transportation in case systems (Moinard *et al* 2003). The interaction between type of production and use of liquid feeding or number of meals, as described earlier, might demonstrate the overall effect of stabile environmental and feeding related solutions to work against general stress factors as potential triggers for tail biting behaviour.

The interaction effect found of further elevated risk for TBD caused by larger group size among from-birth-to-slaughter-farms and by having only finisher pigs with smaller group size, is difficult to explain. It was shown that farms having units for all ages of pigs most commonly had smaller group sizes (less than 10 pigs) in the finisher pens, whereas farms having only finisher pigs had moderate to large group sizes (ten pigs or more) in the finisher pens. There might have been a third unknown factor causing this effect such as diverse technical, environmental or feeding related management solution in farms having one of the two production types. These kind of three dimensional interactions remained unsolved because there were too few farms for statistical analysis and therefore no regression models that covering all the relevant risk factors. Taylor *et al* (2012) observed that even farms with good management practices regarding prevention of tail biting might have deficiencies in other areas influencing the overall risk of what? on the farm.

Risk factors from the diet study

In this study, purchased compound feeds (PCF) fed in the grower unit were associated with increased risk for TBD. Giving PCF to pigs at the grower stage might be due to the practicality, or an attempt to increase diet quality or digestibility, aiming at achieving the optimal daily growth potential. However, Berrocoso *et al* (2012) questioned the benefit of complexity of feeds in the starter phase. PCF are usually supplemented with pure amino acids and minerals as premix, which makes them more nutrient dense than farm made mixtures. Weaner pigs are suggested to suffer from endotoxin stress if fed high-energy dense diets, causing pigs to become more predisposed to become tail-bitten (Jäger 2013). Moreover, PCF are usually pelleted, a form of feed that has been connected to increasing risk for tail biting in long-tailed pigs (Hunter *et al* 2001), although not in this study.

Use of wheat and use of PFC were interconnected because wheat was included in almost all PCF for its higher energy value and digestibility in young animal compared to barley and oat, which are the most common grains used in farm made feed mixtures. Use of wheat for grower pigs was found to be a risk factor for TBD although, whereas all case farms had it included in the diet, this was also true for two thirds of the control farms. It is concluded that finding use of wheat as risk factor is a confounding effect of usage of PFC, not necessarily a true risk associated with provision of the separate ingredient by itself.

There are some findings in the literature of an association between liquid whey in feeds and tail biting (Holmgren & Lundeheim 2004). In our study whey was reported to be used only as dry condensed powder, mostly as an ingredient of PCF or protein concentrate. It was not used with liquid feeding, so there was no interaction between liquid feeding and whey in determining the risk of TBD. Dry whey increased the risk for TBD in dry feeding systems among grower pigs. Although whey is shown to have beneficial effects on growth after weaning (de Lange *et al* 2006), possibly due to its high lactose content helping the shift from maternal milk to external feed source (Berrocoso *et al* 2012), whey could be a risk factor for tail biting because it has been reported to have varying sodium and potassium content and might induce salt poisoning if water supply is limited (de Lange *et al* 2006). A variable level of NaCl in the diet is suggested to be associated with tail biting behavior (Fraser 1987), and salt poisoning is more common in farms having tail biting (Moinard *et al* 2003). An interaction between PCF and whey seems likely, but remains unknown because we had too few observations for further analyses.

Conclusions and animal welfare implications

EU Commission Directive (EC 2001/93, article 8 of the annex) states: “*Neither tail docking …… must be carried out routinely but only where there is evidence that injuries to ….. other pigs´ ears or tails have occurred. Before carrying out these procedures, other measures shall be taken to prevent tail biting and other vices taking into account environment and stocking densities. For this reason, inadequate environmental conditions or management systems must be changed.*” In order to practice pig production in Europe within EU legislation as intended, farmers are obliged to first adjust the environment for the benefits of the pigs and, only if this is impossible and there is evidence of tail biting wounds, is there the possibility to tail-dock the pigs. In the light of our results the risk factors seem to be mainly identical among short and long-tailed pigs. The nutritional risk factors operate through interactions with environmental and management based risk factors, but with relatively lower odds. This study gives the farmers tools to manage the potentially higher risk for tail biting among the long-tailed pigs in order to better conform to EU legislation. Minimizing these risk factors might improve the welfare of pigs by allowing them to fulfil their behavioural and nutritional needs that otherwise might lead to unwanted behaviour like tail biting.

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Table I General descriptors about the whole farm and of separate units of those farms, based on questionnaire answers by the farmers.

	Units			
	farm	piglet	grower	finisher
No. of farms	78	46	39	61
No. of adult animals at farm, mean ± SD	469 ± 650	272 ± 490	323 ± 569	575 ± 698
No. of sows at farm, mean ± SD	63 ± 205	107 ± 265	98 ± 282	64 ± 230
No. of finishers at farm, mean ± SD	398 ± 582	152 ± 238	212 ± 326	502 ± 620
Breed of the pigs, % [1]				
Landrace	26,9	28,3	26,1	29,5
2-crossbred	50,0	56,5	56,5	47,5
3-crossbred	46,2	37,0	23,9	47,5
Other	3,8	4,3	4,3	3,3
Analysis of feeds or raw materials available, % [2]				
Yes	74,4	72,1	56,5	77,0
No	19,2	27,9	21,7	14,8
How often are feeds or raw materials analysed, %				
From every new material fed	11,5	2,2	6,5	13,1
Yearly from every harvest	61,5	65,2	50,0	60,7
More seldom than mentioned above	3,8	4,3	4,3	4,9
Either no analysis or usage of full concentrates	23,1	28,3	39,1	21,3
Who makes the feeding recipes, % [2]				
Farmer	29,5	41,3	28,3	24,6
Feeding company	37,2	34,8	28,3	37,7
Farmer and feeding company together	28,2	23,9	26,1	32,8
Advisor	3,8	0,0	2,2	3,3
Someone else	1,3	0,0	0,0	1,6
Production type, %				
From birth to slaughter	46,2	69,6	56,5	55,7
Specialized single type of production	53,8	30,4	28,3	44,3
Is feeding automatizated, % [2]				
Complitely	38,5	10,9	8,7	47,5
Partly	30,8	47,8	41,3	27,9
Not at all	26,9	34,8	34,8	23,0
What kinf of tail biting is there at farm, % [2]				
Continuous	1,3	2,2	0,0	1,6
From time to time	61,5	41,3	39,1	73,8
No tail biting at any time	33,3	50,0	45,7	23,0
What proportion of pens have tail biting incidents, % [3]				
Less than half of the pens	100,0	100,0	100,0	100,0
More than half of the pens	0,0	0,0	0,0	0,0
How many pigs have being bitten in the pens, % [3]				
A few pigs	91,8	95,0	94,4	91,1
Half of the pigs	4,1	0,0	0,0	4,4
Almost all pigs	4,1	5,0	5,6	4,4

[1] Farm can have more than one breed of pigs

[2] The missing proportion are farms with no data available

[3] Includes only those farms which have tail biting

Table II Distribution of farms and statistical significance within risk factors found to have association with tail biting damage (TBD) status in the feeding study.

Factors	Categories	No. Cases	%	No. Controls	%	Statistical significance		
Piglet unit (0-10kg)	total no. of farms	n=15		n=31		χ^2 / G / F	df	Sig.
Slatted pen floor (fully or partly)	No	3	20,0	24	58,7	13,7	1	***
	Yes	12	80,0	7	22,6			
Area of slatted floor	0 %	3	20,0	24	77,4	14,4	2	**
	1 - 49 %	8	53,3	4	12,9			
	50 - 100 %	4	26,7	3	9,7			
Number of finisher pigs at farm [1]	mean±SD	282	± 203	89	± 230	7,662	1;44	**
Weaner unit (11-30kg)	total no. of farms	n=14		n=25				
Slatted pen floor (fully or partly)	No	1	7,1	13	52,0	7,8	1	**
	Yes	13	92,9	12	48,0			
Area of slatted floor	0 %	1	7,1	13	52,0	11,2	2	**
	1 - 49 %	9	64,3	11	44,0			
	50 - 100 %	4	28,6	1	4,0			
Number of finisher pigs at farm [1]	mean±SD	350	± 302	135	± 319	4,220	1;37	*
Finisher unit (31-110kg)	total no. of farms	n=36		n=25				
Slatted pen floor (fully or partly)	No	5	13,9	14	56,0	12,2	1	***
	Yes	31	86,1	11	44,0			
Area of slatted floor	0 %	5	13,9	14	56,0	12,5	2	**
	1 - 49 %	26	72,2	10	40,0			
	50 - 100 %	5	13,9	1	4,0			
Pigs in one pen	less than 10	14	38,9	17	68,0	5,0	1	*
	ten or more	22	61,1	8	32,0			
Liquid feeding	No	14	38,9	18	72,0	6,5	1	*
	Yes	22	61,1	7	28,0			
Meals offered / day	1 to 2 or to appetite	11	30,6	16	64,0	6,7	1	*
	>2 but not to appetite	25	69,4	9	36,0			
Presence of bedding	Yes	18	50,0	23	92,0	11,8	1	*
	No	18	50,0	2	8,0			
Number of finisher pigs at the farm [1]	mean±SD	729	± 692	174	± 268	14,495	1;59	***
Type of production	from birth to slaughter	16	44,4	18	72,0	4,5	1	*
	only finishers	20	55,6	7	28,0			

Sig. *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$

Table III Univariate logistic regression, magnitude of the risk expressed as odds ratios (OR) and model statistics of the risk factors found for tail biting damage (TBD) status from the feeding study.

Factors	Categories	Ref.	Unadjusted (crude) OR	CI (95%)	Hit ratio %	Cox & Snell R^2	Model Sig.
Piglet unit (0-10kg)							
Slatted pen floor (fully or partly)	No	†	1,0				
	Yes		13,7	3,0 - 62,7	78,3	26,6	0,001
Area of slatted floor	0 %	†	1,0		78,3	26,9	
	1 - 49 %		16,0	2,9 - 87,4			0,001
	50 - 100 %		10,7	1,6 - 72,7			0,016
Number of finisher pigs at farm [1]	mean±SD		1,005	1,001 - 1,009	80,0	16,5	0,025
Weaner unit (11-30kg)							
Slatted pen floor (fully or partly)	No	†	1,0				
	Yes		14,1	1,6 - 124,6	66,7	20,8	0,017
Area of slatted floor	0 %	†	1,0		71,8	24,9	
	1 - 49 %		10,6	1,2 - 97,6			0,037
	50 - 100 %		52,0	2,6 - 1033,8			0,010
Number of finisher pigs at farm [1]	mean±SD		1,002	1,000 - 1,005	64,1	9,6	0,077
Finisher unit (31-110kg)							
Slatted pen floor (fully or partly)	No	†	1,0				
	Yes		7,9	2,3 - 27,0	73,8	18,3	0,001
Area of slatted floor	0 %	†	1,0		73,8	18,8	
	1 - 49 %		7,3	2,1 - 25,5			0,002
	50 - 100 %		14,0	1,3 - 150,9			0,030
Pigs in one pen	less than 10	†	1,0				
	10 or more		3,3	1,1 - 9,8	63,9	8,0	0,028
Liquid feeding	No		1,0				
	Yes		4,0	1,3 - 12,1	65,6	10,3	0,013
Meals offered / day	1 to 2 or to appetite	†	1,0				
	>2 but not to appetite		4,0	1,4 - 11,9	67,2	10,5	0,011
Use of bedding	Presence	†	1,0				
	Absence		11,5	2,4 - 56,2	67,2	19,6	0,003
Number of finisher pigs at the farm [1]	mean±SD		1,004	1,002 - 1,007	78,7	30,4	0,002
Type of production	from birth to slaughter	†	1,0				
	only finishers		3,2	1,1 - 9,6	62,3	7,3	0,036

Ref. reference category

Sig. *** *P* < 0.001; ** *P* < 0.01; * *P* < 0.05

Table IV Distribution of farms and statistical significance within risk factors found to have association with tail biting damage (TBD) status in the diet study.

Factors	Categories	No. Cases	%	No. Controls	%	Statistical significance [1]		
Piglet unit (0-10kg) [2]	total no. of farms	n=9		n=15		χ^2 / G / F	df	Sig.
Weaner unit (11-30kg)	total no. of farms	n=10		n=19				ns
Use of purchased compound feed	No	2	20,0	12	63,2	4,9	1	*
	Yes	8	80,0	7	36,8			
Use of wet or concentrated whey [1]	No	3	37,5	10	83,3	4,4	1	*
	Yes	5	63,5	2	16,7			
Use of wheat	No	0	0,0	6	31,6	3,980	1	*
	Yes	10	100,0	13	68,4			
Finisher unit (31-110kg) [2]	total no. of farms	n=24		n=20				ns

*** P<0.001; ** P<0.01; * P<0.05; ns P>0.05

im=impossible to measure

[1] Farms that used unknown concentrated protein source were not included, n=9

[2] No statistically significant risk factors were found

Table V Univariate logistic regression, magnitude of the risk expressed as odds ratios (OR) and model statistics of the risk factors found for tail biting damage (TBD) status from the diet study.

Factors	Categories	Ref.	Unadjusted crude OR	CI (95%)	Hit ratio %	Cox & Snell R^2	Model Sig.
Piglet unit (0-10kg)							
Weaner unit (11-30kg)							
Use of purchased compound feed	No	†	1,0				
	Yes		6,9	1,1 - 41,8	69,0	16,3	*
Use of wet or concentrated whey 1	No	†	1,0				
	Yes		8,3	1,03 - 67,1	75,0	20,1	*
Use of wheat	No	†	1,0				
	Yes		im	im	im	im	im
Finisher unit (31-110kg)							

Ref. reference category

Sig. *** *P* < 0.001; ** *P* < 0.01; * *P* < 0.05

[1] Farms that used unknown concentrated protein source were not included, n=9

im=impossible to measure

Figure I The frequency distribution of average annual tail biting damage level (TBD mean) of the farms. 1 = no TBD, 2 = some TBD (1-5% of the pigs) , 3 = plenty of TBD (6-19% of the pigs), 4 = lots of TBD (over 20% of the pigs). N = 2163 farms. Dashed lines point out the lower limit of TBD mean selected for case farms in year 1 (- - - -) and year 2 (-.-.-.). Solid line shows the upper limit of TBD mean accepted for control farms in both the years.

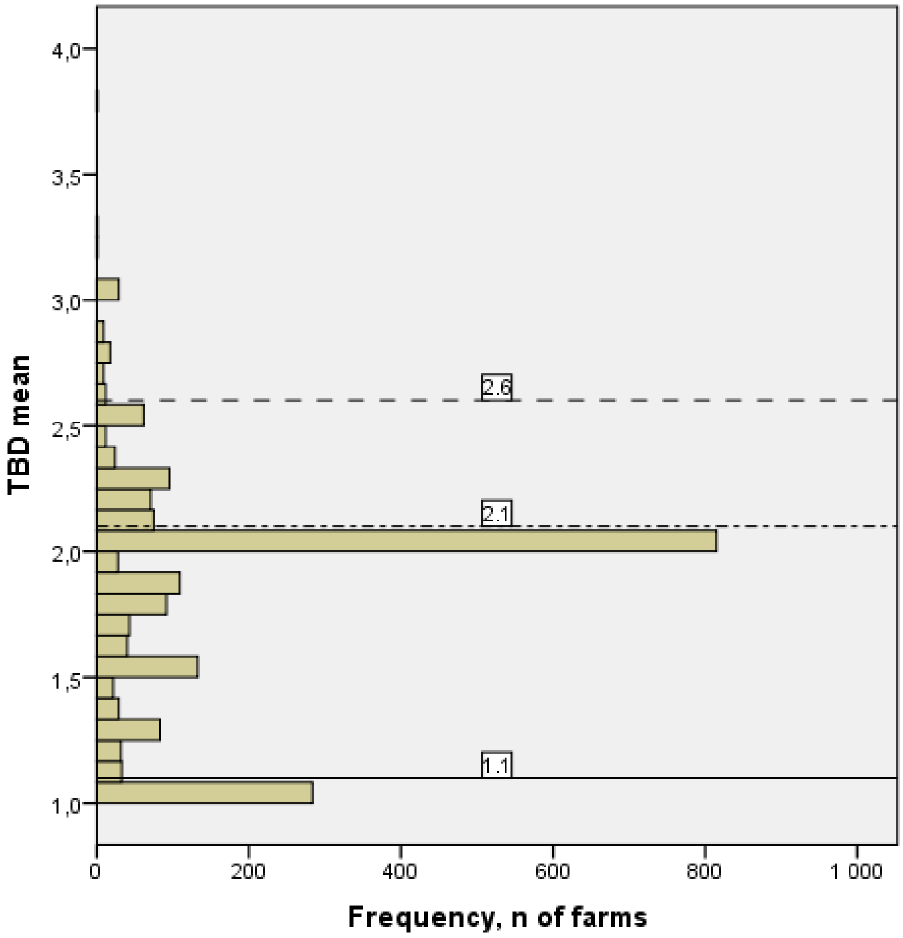

Figure II

IMPORTANT QUESTION! Do we need figures (bar charts) for interactions? There is possible to put interactions into bars using **number of observation** in each strata (=possible combination of answer choices) compared to non-stratified category. At this moment, these number of observations are not presented in the text, only the statistical values and significances are. But if the text is enough to describe the interactions and their odds ratios, I would rather not include any extra figures. Showing all interactions needs 8 figures. **What do you all think?**

(one example of presenting this is below, without any OR:s or significances at this point, because they are difficult to include)