**Annotated Bibliographies**

*Organized into two major themes; Articles under ‘Why the behaviour occurs’ primarily focus on the influences on the behaviour, while articles under ‘Describing the behaviour’ focus on characterization and description of stereotypies. One article is under both categories as it contributes equally to both.*

*Secondary article: Why the behaviour occurs*

**Lawrence, A. B., & Terlouw, E. M. C. (1993). A review of behavioral factors involved in the development and continued performance of stereotypic behaviors in pigs. *Journal of Animal Science*, *71*(10), 2815–2825.** [**https://doi.org/10.2527/1993.71102815x**](https://doi.org/10.2527/1993.71102815x)

**Summary:** This article reviews different factors that may cause pigs to develop stereotypies under restricted feed intake. The review places these factors into two broad categories: those specific to feeding and those not specific to feeding. The primary factor, specific to feeding, that leads to the development of oral stereotypies in pigs is feeding motivation. When the amount of feed is restricted this in turn increases feeding motivations, primarily hunger, which leads to the development of abnormal behaviours. Furthermore, these oral stereotypies, such as bar biting and vacuum chewing, tend to occur after the animal has been fed. The article suggests that this positive feedback, whereby feeding induces oral stereotypies, may be because food creates a temporary increase in feeding motivation because the pig is now receiving an incentive (food) for its feeding behavior. However, since the pig is not receiving sufficient food, once it finishes feeding it directs this feeding motivation towards other pigs or objects.

Of the factors not specific to feeding, a restrictive physical environment that limits the behaviors a pig can perform is important in the development of oral stereotypies. The review characterizes this as a process of sensitization. Seeing that the pigs are continuously exposed to a restrictive environment where they cannot perform their natural free-range behaviors, like foraging. Therefore, the pig can only perform a few behaviours permitted by the environment that still provide them with some sort of incentive. As the environment continues to be restrictive, behaviours will gradually become more monotonous.

This provides significant support for the fact that although the motivations behind stereotypies may be the same, the type of environmental constraints placed on the pig will influence what type of stereotypies it will develop. In the case of housed pigs, the limited space causes the pigs to primarily develop oral stereotypies.

**Contribution:** This review provides an in-depth overview of the different factors that may lead to the development of stereotypies. Not only does the article provide reasons for the development of these behaviours, but it also suggests why these behaviours are primarily oral. As a review, this article has been cited by most of the primary literature on pig stereotypical behaviour. This is significant because although the article is relatively old, the information remains relevant. The review also highlights the importance of making changes in the pigs’ environment, like decreasing stocking density and implementing optimal environmental enrichment solutions to prevent oral stereotypies.

*Primary article: Why the behaviour occurs*

**Breuer, K., Sutcliffe, M. E. M., Mercer, J. T., Rance, K. A., O’Connell, N. E., Sneddon, I. A., & Edwards, S. A. (2005). Heritability of clinical tail-biting and its relation to performance traits. *Livestock Production Science*, *93*(1), 87–94.** [**https://doi.org/10.1016/j.livprodsci.2004.11.009**](https://doi.org/10.1016/j.livprodsci.2004.11.009)

**Summary:** Breuer et al. (2005) investigated the heritability of tail-biting behaviour by comparing the incidence of tail-biting behaviour between two pig breeds; Large White (LW) and Landrace (LR). Researchers identified tail-biting individuals through an observational study that took place over a year. Over the year researchers would do routine checks on a commercial farm, observing 9018 pigs in total, of these 3177 of them were the Large White breed, and 5841 of them were the Landrace breed. Researchers made sure that both pig breeds were under the same environmental conditions. This study characterized tail-biting as a biting behaviour that results in the victim’s tail being injured, therefore, only when the tail was bleeding would they characterize the biting pig as a tail-biter.

A pedigree of all the pigs on the farm was obtained from farm records. These pedigrees indicated the relatedness between tail-biting individuals. Researchers also obtained breed and gender of all pigs from farm records. Finally, physical traits including Lean tissue growth rate (LTGR), and back fat thickness were measured for tail-biting individuals.

By ascertaining how many individuals from each breed were tail-biters researchers were able to determine that the Landrace pig breed has a significantly higher incidence of tail-biting individuals.

Therefore, the breed with a higher risk of tail-biting is Landrace. Consequently, researchers

used the pedigree from farm records to trace the possible inheritance of tail-biting behaviour. Breuer et al. (2005) concluded that tail-biting is heritable in the Landrace pig breed but not in the Large White.

Furthermore, from the data on physical traits, researchers also found that Landrace pigs had on average a significantly higher LTGR and a less back fat. They imply that the heritability of tail-biting could be correlated to these physical traits. Moreover, in order to obtain lean meat these physical traits are typically selected for by farmers. This could imply that tail-biting behaviour in the Landrace breed has also been somewhat unconsciously selected for.

**Contribution:** This study is important because it focuses on the heritability of oral stereotypies rather than the environmental influences. Although the study, like many others, states that the behaviour is a multifactorial problem, it focuses on the genetic makeup of pigs that may predispose them to tail-biting behaviours. The results show that tail-biting is a heritable behaviour in the Landrace breed, which supports the idea that this behaviour may be influenced at a genetic level. Since physical traits are likely the cause of this heritability study suggests that by selecting against the physical traits, tail-biting behaviour could also be selected against.

*Secondary article: Why the behaviour occurs*

**Godyń, D., Nowicki, J., & Herbut, P. (2019). Effects of environmental enrichment on pig welfare—A review. Animals, 9(6), 383.** [**https://doi.org/10.3390/ani9060383**](https://doi.org/10.3390/ani9060383)

**Summary:** This article reviews various enrichment materials that were investigated in previous studies for their ability to improve pig welfare. The objective of the review is to compile information from previous studies on the effects of enrichment objects on pig welfare and summarize what the major findings were. The study focuses on two broad categories pertaining to the stage at which the environmental enrichment was given. These categories are sucker/weaned piglets and fattening pigs. For each stage the review summarizes major studies based on what enrichment was used and the effect it had. Throughout the review the article continuously references the Commission Recommendation (EU) which categorizes environmental enrichment tools into three major categories: ‘optimal’, ‘suboptimal’, and ‘of marginal interest’. Examples of optimal materials are straw and green fodder. Godyń et al. (2019) explains that these materials are excellent for pig enrichment because they allow pigs to perform natural behaviours. Godyń et al. (2019) uses the Commission Recommendation to categorize the materials that were used in previous studies into one of the three categories. The major materials that were found to have a direct effect in reducing tail and ear-biting in fattening pigs was straw bedding, metal chains, pieces of wood attached to metal chains, wood shavings, and fresh birch wood. For sucker/weaned pigs the major findings from previous studies were that wood shavings, sisal rope, and plastic toys could reduce oral manipulations and decrease severe tail-damages, and straw bedding could increase level of exploration. It is important to note that not just ‘optimal’ materials have a positive effect.

Although the review focuses on overall pig welfare, it is significant because oral stereotypies have been found to arise from stressful conditions that lack enrichment, and as shown in previous studies adding enrichment can reduce the oral stereotypies and their subsequent injuries.

**Contribution:** This is the most recent review on swine enrichment. It is compiling the most relevant literature on the effects of environmental enrichment on pig welfare, which concerns oral stereotypies that are known to be caused by barren environments. The article uses previous studies to highlight the fact enrichment can decrease abnormal behaviours. By compiling this information, the article is also able to deduce that enrichment can be beneficial at all stages of a pig’s life. The importance of having this review is that it is necessary to use methods such as enrichment rather than invasive procedures, like tail-docking, to limit tail-biting.

*Primary article: Why the behaviour occurs*

**Munsterhjelm, C., Heinonen, M., & Valros, A. (2016). Can tail-in-mouth behaviour in weaned**

**piglets be predicted by behaviour and performance? *Applied Animal Behaviour***

***Science*, *184*, 16–24.** [**https://doi.org/10.1016/j.applanim.2016.08.013**](https://doi.org/10.1016/j.applanim.2016.08.013)

**Summary:** Munsterhjelm et al. (2016) aimed to determine whether pigs who performed tail-in-mouth (TIM) behaviour exhibited any other identifiable behaviours or physical characteristics prior to their performance of TIM behaviour. Previous studies hypothesized that before tail-biting pigs will often perform TIM behaviours (Taylor et al., 2010), therefore, this study wanted to identify possible behavioural or physical indicators that precede TIM.

This was an observational study through video recordings on 88 pigs. Study used continuous focal sampling and instantaneous scan sampling. Researchers created two ethograms for each of the sampling techniques. TIM was described as an oral manipulation of the tail that does not result in tail injury.

Munsterhjelm et al. (2016) aimed to focus on individuals, therefore, pigs were individually marked. Study focused on individuals’ behaviours at 4 weeks of age before any TIM was observed, and at 9 weeks of age when TIM had occurred at least once in a group. Based on continuous focal sampling at 9 weeks of age individuals were categorized as either TIM performers (P), TIM receivers (R) or neutral pigs (N). By analysing video recordings of pigs at 4 weeks of age researchers observed that P pigs were significantly more active and would explore their environment and pen mates significantly more. This showed that TIM behaviours are likely to be predicted in individuals who are more active and social. Furthermore, it showed that TIM is associated with exploratory behaviours and TIM might be a way for pigs to redirect exploratory behaviours.

Researchers concluded that there was no significant influence of gender on TIM behaviour.

Moreover, researchers weighed the pigs at birth, 4 weeks, and 9 weeks. The only significant difference observed in weight between the P, R, and N categories was at birth, whereby P pigs were born at a significantly lower weight.

**Contribution:** This study advances our understanding of behaviours and physical characteristics associated with TIM, which is often seen by studies as a precursor to tail-biting (Taylor et al., 2010). By observing a higher individual activity level prior to TIM, this study somewhat supports the findings by Statham et al. (2009), which found a higher activity level prior to tail-biting outbreaks. Moreover, this study also shows that TIM has a strong correlation to exploratory behaviours, and previous studies have found that a restriction placed on exploratory behaviours may lead to oral stereotypies (Godyń et al. 2019). This study contradicts other studies that found a correlation between gender and oral manipulation.

*Secondary article: Describing the behaviour, Why the behaviour occurs*

**Taylor, N. R., Main, D. C. J., Mendl, M., & Edwards, S. A. (2010). Tail-biting: A new**

**perspective. *The Veterinary Journal*, *186*(2), 137–147.**

[**https://doi.org/10.1016/j.tvjl.2009.08.028**](https://doi.org/10.1016/j.tvjl.2009.08.028)

**Summary**: This review uses information from previous studies on tail-biting to outline three forms of tail-biting. Prior to this review studies used very different terminology for tail-biting behaviour, thereby making it difficult to compare studies. Taylor et al. (2010) analysed the behaviours observed in these previous studies and was able to describe 3 forms of tail-biting: ‘two-stage tail-biting’, ‘sudden-forceful tail-biting’, and ‘obsessive tail-biting’. This is significant because it allows future studies to identify tail-biting according to these forms. Taylor et al. (2010) also identified that each form may be influenced by different factors.

The first form named ‘Two-stage tail-biting’ is when a pig displays a ‘tail-in-mouth’ behaviour prior to a tail-biting stage that results in tail lesions. Taylor et al. (2010) deduces from previous studies that what leads to this form is likely a lack of environmental enrichment, which limits the pigs’ natural exploratory behaviours.

The second form named ‘sudden-forceful tail-biting’ is when there is no precursor behaviour to biting. The pig just impulsively bites the tail of a pen mate. Taylor et al. (2010) recognises that all previous accounts of this form of tail-biting result in injury. Taylor et al. (2010) infers that this form likely occurs because the pigs are frustrated and need to compete with one another. The review notes that in previous studies this form was often grouped in with cannibalism. Moreover, this form can be mitigated by removing pigs that are biting.

The final form named ‘obsessive tail-biting’ is when there is an abnormally high incidence of tail-biting occurring that results in multiple tail lesions. Taylor et al. (2010) characterises this particular form as stereotypic because the pig is spending a majority of its time doing the behaviour. Based on previous studies, the review suggests that there is possibly a genetic factor influencing this form.

**Contribution:** There are so many different definitons of tail-biting which makes it difficult to compare studies and thus implement findings into preventative treatments. This review classified previously observed types of tail-biting behaviours into three major categories, which have been used by many studies since this studies publication.

The form called ‘obsessive tail-biting’ is of particular importance because its definition allows us to distinguish certain forms of tail manipulation from stereotypies. Taylor et al. (2010) also summarises what influences may lead to different forms of tail-biting, thus, what particular methods should be implemented to prevent a specific form of tail-biting.

*Primary article: Describing the behaviour*

**Brunberg, E., Wallenbeck, A., & Keeling, L. J. (2011). Tail biting in fattening pigs: Associations between frequency of tail biting and other abnormal behaviours. *Applied Animal Behaviour Science*, *133*(1–2), 18–25.** <https://doi.org/10.1016/j.applanim.2011.04.019>

**Summary:** This article investigated the association between the frequency of tail-biting (TB) and other abnormal behaviours such as ear biting, bar biting, and non-biting behaviours categorized under ‘other abnormal’. Brunberg et al. (2011) aimed to investigate this association by placing individual pigs into different performer and receiver categories based on observations. The performer categories divided pigs based on the frequency of tail bites/hour: high-performers, low-performers, and non-performers. The receiver categories divided pigs based on the frequency of received tail bites/hour: high-receivers (HR), low-receivers (LR), and non-receivers (NR). Brunberg et al. (2011) created an ethogram containing the 3 severity categories of TB: mild TB, moderate TB, and severe TB. The ethogram also includes ‘tail in mouth’ behaviour, and other oral stereotypical behaviours (ear and bar biting).

Results showed that HP pigs performed the highest proportion of severe TB, which implies that they are the greatest health-risk. Results further showed that tail-biters performed more ear biting and more bar biting. Hence, individuals performing TB are generally displaying stereotypies focused on biting behaviour.

Results showed that HR also received a higher number of ‘other abnormal’ behaviours. Thus, some individuals may be predisposed to receive more abnormal behaviours and developing severe injuries.

This study was significant because it showed a clear association between tail-biting and other abnormal behaviours, especially other biting behaviours. This study provides a precise framework for identifying these behaviours, which is useful for the reliable identification and removal of high-risk individuals to limit tail injuries and spread of disease. Furthermore, the association between biting behaviours implies that they arise from the same motivational background. In addition, it also suggests that what is being bitten is not significant. Therefore, perhaps tail-biting could be limited if certain biting or feeding enrichment tools were distributed.

**Contribution:** This article provides support for the fact that oral stereotypies tend to occur together. This suggests that these stereotypies could, to some extent, have the same motivational background. This article also provides an ethogram with descriptions for various stereotypical behaviours, which is useful in identifying these behaviours and being able to quickly distinguish between levels of severity for tail-biting. Identifying the severity of tail-biting is important because those pigs who perform severe tail bites are also the high performers that display the greatest proportion of tail-biting behaviours. Identifying and potentially removing these high performers is important in limiting tail injuries.

*Primary article: Describing the behaviour*

**Hakansson, F., & Bolhuis, J. E. (2021). Tail-biting behaviour pre-weaning: Association between**

**other pig-directed and general behaviour in piglets. *Applied Animal Behaviour***

***Science*, *241*, 105385.** [**https://doi.org/10.1016/j.applanim.2021.105385**](https://doi.org/10.1016/j.applanim.2021.105385)

**Summary:** The study by Hakansson and Bolhuis (2021) investigates tail-biting behaviour in farm piglets, and whether it is associated with other pig-directed behaviours, activity, and body weight development. Study was conducted because the precursor behaviour of tail-biting, tail-in-mouth, develops at a younger age, and mild forms of tail-biting damage have been observed in piglets before weaning. Behavioural observations were conducted by video analysis of 284 piglets. Individuals were identified by ear tags. Video analysis was done with two types of sampling: instantaneous scan sampling and continuous sampling for general behaviours and pig directed behaviours, respectively. An ethogram of pig-directed behaviours including tail-biting and ear-biting was used for the continuous sampling. For each behaviour, the number of bouts, duration, performer, and receiver were recorded. This study characterizes tail-biting as the behaviour in which one pig’s oral manipulation leads to tail wounds in another pig’s tail.

For scan sampling, the general behaviour, described by an ethogram, and the individual performing the behaviour was recorded.

Biters were classified as low-biter (LB), high-biter (HB), and non-biter (NB). Pigs were weighed several times over the course of the study.

Biters, both LB and HB, were found to be more active and social with their litter mates. This is significant as it suggests a connection between this oral behaviour and social exploration.

HB biters also performed the most ‘other biting’ and ‘sow directed tail-biting’ behaviours.

The biters and non-biters did not differ in their birth weight. However, HB had a lower average daily gain (ADG) during lactation, therefore, they might have had poor nutrition. It was suggested by Hakansson and Bolhuis (2021), that the biting behaviour could’ve arose to compensate for being less competitive when they are trying to access udder, or simply because they are hungry. This study found no effect of sex on tail-biting prevalence.

**Contribution:** This study was chosen because it determined physical and behavioural variations in piglets depending on whether they exhibited tail-biting behaviour. Piglets that did bite were found to engage in other oral manipulatory behaviours, be more socially and generally active, and be smaller. Thus, this piglet study supports the association between tail-biting and other biting behaviours observed in older pigs. Study shows differences between biters and non-biters prior to weaning, which could suggest motivation for behaviour begins early. This study can be applied by farmers as a preventative measure for tail-biting behaviour by removing high-risk piglets.

*Primary article: Describing the behaviour*

**Statham, P., Green, L., Bichard, M., & Mendl, M. (2009). Predicting tail-biting from behaviour of pigs prior to outbreaks. *Applied Animal Behaviour Science*, *121*(3–4), 157–164.** [**https://doi.org/10.1016/j.applanim.2009.09.011**](https://doi.org/10.1016/j.applanim.2009.09.011)

**Summary:** Previous studies observed an increase in activity levels during a tail-biting outbreak. The study by Statham et al. (2009) wanted to determine whether there was also an increase in activity prior to an outbreak that could be used to predict it. The objective was to determine any possible indicators of an outbreak. Statham et al. (2009) explains that predicting an outbreak allows farmers to intervene, thereby limiting/preventing injuries.

This was a longitudinal observational study on 700 farmed pigs (divided into 24 groups) across their entire life. Pigs were observed both directly and through video recordings. All occurrence group sampling and instantaneous scan sampling were used, and an ethogram was made using previous studies on tail-biting. Based on observations, the groups of pigs were categorized as either ‘No outbreak’ (NO), ‘Underlying outbreak’ (UO), or ‘Severe outbreak’ (SO).

By analysing recordings prior to an outbreak, researchers compared behaviours between NO and SO groups. The SO groups had a significantly higher number of pigs standing, and a significantly lower number of pigs being inactive. This reveals that a higher level of groups activity is an indicator of an outbreak. However, early direct observations revealed no difference in activity. Therefore, the higher level of activity is transitory and occurs days before an outbreak.

In the NO and UO groups a significantly higher number of pigs were observed with their tails tucked under, therefore, tails tucked under is a possible indicator.

Tail manipulation was not found to be an indicator since no differences in the levels of tail manipulation between the groups prior to an outbreak was observed.

Finally, the most consistent indicator of an outbreak found by Statham et al. (2009) was the presence of a tail-bitten runty pig characterized as an ‘indicator pig’, groups with this pig always ended up having an outbreak.

**Contribution:** This study reveals a new way to limit or entirely prevent tail injuries by predicting outbreaks using indicators, like the tail-bitten runty pig. Although it had been previously discovered that high activity levels are present during an outbreak, this study was able to determine that it also occurs prior to an outbreak. Article was included because predicting an outbreak on a commercial farm would limit the negative economical and welfare impacts of the outbreak. This article contradicts the previously hypothesized idea that ‘tail-in-mouth’ is a behavioural precursor to tail-biting. Further investigation into the relationship between ‘tail-in-mouth’ and tail-biting is needed.

*Primary article: Describing the behaviour*

**Diana, A., Carpentier, L., Piette, D., Boyle, L. A., Berckmans, D., & Norton, T. (2019). An ethogram of biter and bitten pigs during an ear biting event: First step in the development of a Precision Livestock Farming tool. *Applied Animal Behaviour Science*, *215*, 26–36.** [**https://doi.org/10.1016/j.applanim.2019.03.011**](https://doi.org/10.1016/j.applanim.2019.03.011)

**Summary:** The study by Diana et al. (2019) takes a more in-depth look at ear-biting (EB) behaviour. The study aims to identify and describe specific movements and vocalisations associated with either the performer or the victim during an EB event so that future researchers may be able to develop an algorithm in Precision Livestock Farming technology (PLF), which can warn farmers that EB will, or is, occurring. Diana et al. (2019) explains how PFL is a technology that continuously monitors behaviours and can identify certain behaviours based on specific movements and/or sounds. Diana et al. (2019) conducted an observational study using video recordings for 300 pigs in the weaner stages. Video recordings were analysed for specific movements/sounds when there was a high level of activity. The relative times spent on each of the behaviours was identified using observations and statistical analysis.

The study used observations to create two separate ethograms; one describing behaviours performed by the bitten pig and the other describing behaviours performed by the biter.

For the bitten pig the physical behaviours were categorised as either ‘Avoidance’, which included moving away, or ‘Aggression’, which included biting and head knocking. The vocal behaviours identified were scream, grunt, and squeal. Diana et al. (2019) noted that these vocalisations are significant for PLF because they have characteristic sounds.

For the biter only physical behaviours were identified, and these were categorized into ‘ear-in-mouth with response’, which includes chewing, ‘ear-in-mouth without response’, and ‘EB attempt'. Diana et al. (2019) explains how the ‘without response’ and ‘attempt’ behaviours are significant for PFL to prevent damaging EB from occurring in the first place. The study goes on to relate these newly defined behaviours to a previous review by Taylor et al. (2015) and describes how the classifications of EB are very similar to those for tail-biting.

**Contribution:** This article is the first to identify and describe specific movements and vocalisations performed by biter and bitten pigs during an EB event. The precise characterization of these behaviours allows future researchers to create an algorithm that can be used in PLF technology. This technology will notify farmers of these behaviours, thereby allowing them to remove high-risk individuals. This is significant because according to previous studies ear-biting is becoming a more serious welfare issue. Furthermore, the characterisation of EB behaviours is very similar to that of tail-biting described in previous studies, which supports the fact that the behaviours are similar.