Department of Production Animal Medicine
Faculty of Veterinary Medicine
University of Helsinki
Finland

Reducing tail biting in commercially farmed pigs: experiments on providing wooden objects, paper and rope

Helena Telkänranta

ACADEMIC DISSERTATION

To be presented with the permission
of the Faculty of Veterinary Medicine of the University of Helsinki
for public examination on 25 May 2020
via a videoconference link to be disseminated separately

Helsinki 2020

Supervised by

Professor Anna Valros
Department of Production Animal Medicine
Faculty of Veterinary Medicine
University of Helsinki
Finland

Reviewed by

Professor Xavier Manteca
Department of Animal and Feed Science
School of Veterinary Science
Universitat Autònoma de Barcelona
Spain

Keelin O'Driscoll
Pig Development Department
Teagasc
Moorepark
Fermoy
Co. Cork
Ireland

Opponent

Rick D'Eath
Department of Animal and Veterinary Sciences
Scotland's Rural College
United Kingdom

ISBN 978-951-51-6000-3 (paperback)
ISBN 978-951-51-6001-0 (PDF)
Unigrafia, Helsinki 2020

Abstract

Tail biting is one of the most important animal welfare problems in commercial pig farming. Its severity varies from scratched skin to partially or entirely eaten tails. A similar though less studied problem is ear biting. Tail and ear biting are abnormal behaviours with multifactorial origins. One of the main factors is a scarcity of materials to fulfil pigs' innate need to chew and root, which causes some pigs to redirect these needs at other pigs. Of the materials readily available in large enough quantities for farmers, a substantial layer of straw on the floor is considered best to fulfil these needs and to reduce or prevent tail biting. However, such use of straw is rare in intensive farming because the low consumer price of pork has led commercial farms minimising production costs, and one of the consequences is that most farms use slatted or partly slatted pen floors and manage the manure as slurry, which reduces labour costs but precludes the use of straw bedding. Various objects are used on farms as potential outlets for pigs' needs for oral-nasal manipulation, but their ability to reduce tail biting and to sustain pigs' interest and to reduce tail and ear biting vary widely.

The main aim of the four studies presented in this thesis was to investigate the efficacy of selected materials and object designs in reducing tail and ear biting damage in intensively farmed pigs kept on slatted floors. The studies were carried out on four commercial farms in Finland, and data were collected from a total of 2064 pigs. In each of the studies, experimental treatments represented materials and object designs selected or developed by the experimenters, and control treatments represented the materials and object designs normally used on the farm in question.

In Study I, the main research question was whether pre-weaning exposure to sisal ropes and paper would reduce post-weaning tail biting. In the control treatment, 29 farrowing pens were furnished with a suspended plastic ball, and a small amount of wood shavings were provided twice a day. In the experimental treatment, 30 farrowing pens were furnished with the above and in addition ten pieces of suspended sisal rope, and sheets of non-glossy newspaper were distributed twice a day. After weaning, piglets from both treatments were housed in identical pens with three pieces of suspended rope, a plastic chewing stick and wood shavings twice a day. The main findings were that pre-weaning exposure to the supplementary materials reduced the severity of post-weaning tail biting, and that redirection of oral-nasal behaviours at pen-mates was reduced by current, but not past, exposure to the materials.

In Study II, the main research questions were whether providing growing-finishing pigs with objects made of recently harvested wood would reduce tail biting and whether the same effect could be attained with metal and plastic objects with moderately added complexity. In the control treatment, 17 grower-finisher pens were furnished with a straw rack and a metal chain. There were four experimental treatments, each furnished with the above and additionally with the following: 14 pens with horizontal wooden beams (W), 13 pens with horizontal plastic crosses (P), 15 pens with hanging metal chains in a branching form (B) and 14 pens with all the above objects (WPB). The main findings were that only the wooden objects reduced the prevalence of tail and

ear biting as compared to the control group, and that wooden and plastic objects sustained the interest of the pigs better than metal objects.

In Study III, the main research question was whether a small amount of recently harvested wood (approximately 20cm of horizontal wooden beam per pig) would reduce tail biting in breeder gilts that also were provided with minimal amounts of straw. In the control treatment, 12 breeder gilt pens were furnished with a horizontal piece of commercially sourced dry wood and a metal chain with a moderately complex structure (feeder chain), and long straw was distributed once a day, approximately 20g per pig per day. In the experimental treatment, the above solid objects were replaced with objects of recently harvested wood. The main findings were that there was no significant difference between treatments regarding tail biting; and that the frequency of oral-nasal behaviours targeted at other pigs did not differ between treatments before the provision of the minimal amount of straw, but was lower in the experimental treatment after pigs in both treatments had consumed the straw.

In Study IV, the main research questions were whether a minimal amount of recently harvested wood (approximately 10cm length of wood per pig) would reduce tail biting in growing-finishing pigs that were also provided with a straw rack and whether the same quantity of medium-density polythene objects would have the same effect. In the control treatment, 16 growing-finishing pens were furnished with a straw rack. There were two experimental treatments, each furnished with the above and additionally with the following: 16 pens with horizontal wooden objects (W) and 12 pens with horizontal plastic objects (P). The main findings were that there was no significant difference between treatments in their effects on tail biting; and that the wooden but not plastic objects reduced ear biting and the latency to approach an unfamiliar person in a human approach test, as compared to the control group.

The main conclusions were that it is possible to reduce post-weaning tail biting by adding pre-weaning material for manipulation, but further studies are required to determine the necessary minimum quantity and quality of the materials. Horizontally placed lengths of recently harvested wood can reduce tail and ear biting and potentially also stress in growing-finishing pigs, but further studies are needed on optimal object design and the necessary minimum quantity. The presence of recently harvested wood can slightly add to the beneficial effects of minimal amounts of straw. There also was a finding relevant to general research methodology in this field: the frequency of object-directed behaviours is not the sole reliable predictor of a material’s efficacy in reducing tail biting as the plastic objects elicited object-directed behaviours to the same extent as the wooden objects, but plastic objects did not reduce tail biting.

Yhteenveto (Abstract in Finnish)

Hännänpurenta on yksi keskeisimmistä eläinten hyvinvointia heikentävistä ongelmista kaupallisessa sianlihantuotannossa. Sen vakavuusaste vaihtelee ihonaarmuista osittain tai kokonaan syötyihin häntiin. Toinen samankaltainen ongelma on korvienpurenta, vaikkakin sitä on tutkittu vähemmän kuin hännänpurentaa. Hännän- ja korvienpurenta ovat epänormaalia häiriökäyttäytymistä, joiden taustalla on useita tekijöitä. Yksi keskeisimmistä syistä on riittämätön määrä sellaisia materiaaleja, joilla siat voisivat tyydyttää sisäsyntyistä pureskelun ja tonkimisen tarvettaan, jolloin osa sioista suuntaa nämä käyttäytymismuodot toisiin sikoihin. Niistä materiaaleista, joita maataloustuottajien on mahdollista hankkia riittävinä määrinä, paksu olkikerros lattialla on tehokkain näiden käyttäytymistarpeiden tyydyttämisessä sekä hännän- ja korvienpurennan vähentämisessä. Tällainen oljen käyttö on kuitenkin harvinaista tuotantotiloilla, koska sianlihan matalan kuluttajahinnan takia tuottajien on minimoitava tuotantokustannuksensa, ja yksi yleisesti käytetty keino siihen on lietelantajärjestelmä, jossa karsinoiden lattiat ovat osittain tai kokonaan osaritilää ja joka estää olkien käytön muuten kuin hyvin pieninä määrinä. Sikatiloilla käytetään myös erilaisia pureskeltavia ja tongittavia esineitä, mutta niiden välillä on suuria eroja niiden kyvyssä ylläpitää sikojen mielenkiintoa sekä vähentää hännän- ja korvienpurentaa.

Tämä väitöskirja perustuu neljään tutkimukseen, joiden aiheena oli selvittää, vähentävätkö eräät materiaalit ja niistä muokatut erilaiset esineet hännän- ja korvienpurentaa kaupallisissa tuotanto-olosuhteissa osaritilälattioilla. Tutkimukset tehtiin neljällä suomalaisella sikatilalla, ja väitöskirjan aineisto on peräisin yhteensä 2064 sikayksilöstä. Kussakin tutkimuksessa testatut esineet olivat tutkimuksen tekijöiden valitsemia tai heidän tätä tarkoitusta varten kehittämiään, ja verrokkikäsittelyinä olivat samat esineet ja muut materiaalit, joita kyseisellä tilalla normaalistikin käytettiin.

Tutkimus I:n keskeisin tutkimuskysymys oli se, voiko porsaiden ensimmäisinä elinviikkoina tarjottava lisämateriaali vähentää myöhempää, vieroituksen jälkeisenä aikana tapahtuvaa hännänpurentaa. Verrokkikäsittelyssä oli 29 porsituskarsinaa, joissa kussakin oli ketjussa riippuva muovipallo, ja niihin annettiin pieni määrä kutterinpurua kahdesti päivässä. Koekäsittelyssä oli 30 porsituskarsinaa, joissa kussakin oli edellä mainittujen lisäksi 10 sisalköyttä, ja niihin annettiin sanomalehtipaperia kahdesti päivässä. Vieroituksen yhteydessä molempien käsittelyjen porsaat siirrettiin keskenään samanlaisiin vieroituskarsinoihin, joissa oli 3 sisalköyttä ja muovinen purutikku ja joihin annettiin kutterinpurua kahdesti päivässä. Päätulokset olivat se, että ennen vieroitusta annettu lisämateriaali vähensi vieroituksen jälkeen tapahtuvan hännänpurennan vakavuusastetta, ja se, että lisämateriaalin läsnäolo vähensi suu- ja kärsäkontaktien suuntaamista toisiin porsaisiin, mutta tämä käsittelyjen välinen ero katosi vieroituksen jälkeen, jolloin käsittelyjen välillä ei enää ollut eroa senhetkisessä materiaalitarjonnassa.

Tutkimus II:n keskeisimmät tutkimuskysymykset olivat se, voiko lihasikojen hännän- ja korvienpurentaa vähentää tuoreesta puusta tehdyillä esineillä sekä se, voiko saman vaikutuksen saada aikaan esineillä, jotka on tehty polyeteenimuoviputkista tai metalliketjusta, ja jotka ovat rakenteeltaan hiukan monimutkaisempia kuin muoviputket tai ketju sellaisinaan käytettyinä.

Verrokkikäsittelyssä oli 17 karsinaa, joissa oli olkihäkki ja metalliketju. Koekäsittelyjä oli neljä, ja niissä oli seuraavat esineet: vaaka-asentoisia puunrungon pätkiä 14 karsinassa (W), vaaka-asentoisia muoviputkista tehtyjä ristejä 13 karsinassa (P), riippuvia haarautuvia metalliketjuja 15 karsinassa (B) sekä kaikki edellä mainitut esineet 14 karsinassa (WPB). Päätulokset olivat se, että ainoastaan puuesineet vähensivät hännän- ja korvanpurennan esiintyvyyttä, sekä se, että puu- ja muoviesineet pitivät sikojen mielenkiintoa yllä paremmin kuin metalliesineet.

Tutkimus III:n keskeisin tutkimuskysymys oli se, vähentääkö pieni määrä puuta (noin 20 cm vaaka-asentoista puunrunkoa per sika) kasvatussikojen hännän- ja korvienpurentaa tilanteessa, jossa sioille annetaan myös pieni määrä olki päivittäin. Verrokkikäsittelyssä oli 12 karsinaa, joissa oli vaaka-asentoinen laudanpala ja riippuva pätkä metallista ruokkijan ketjua, ja pitkää olkea annettiin kerran päivässä noin 20 g per sika. Koekäsittelyssä oli 12 karsinaa, joissa oli laudan ja ketjun sijasta vaaka-asentoista tuoretta puunrunkoa. Päätulokset olivat se, että käsittelyjen välillä ei ollut merkitsevää eroa hännän- ja korvienpurennassa ja se, että sikojen toisiinsa suuntaamien suu- ja kärsäkontaktien määrässä oli merkitsevä ero ainoastaan päivittäisen olkien jakamisen jälkeen, jolloin sitä esiintyi koekarsinoissa vähemmän kuin verrokkikarsinoissa.

Tutkimus IV:n keskeisimmät tutkimuskysymykset olivat se, vähentääkö hyvin pieni määrä puuta (noin 10 cm vaaka-asentoista puunrunkoa per sika) lihasikojen hännän- ja korvienpurentaa tilanteessa, jossa karsinoissa on myös olkihäkki, sekä se, saadaanko sama vaikutus aikaan samalla määrällä keskitiheyksistä polyeteenimuoviputkea. Verrokkikäsittelyssä oli 16 karsinaa, joissa oli olkihäkki. Koekäsittelyjä oli kaksi, ja niissä oli seuraavat esineet: vaaka-asentoisia puunrungon pätkiä 16 karsinassa (W) ja vaaka-asentoisia muoviputkia 12 karsinassa (P). Päätulokset olivat se, että hännänpurennassa ei ollut merkitsevää eroa käsittelyjen välillä, ja että muihin käsittelyihin verrattuina puuesineet vähensivät korvienpurentaa sekä nopeuttivat sikojen uskaltautumista koskettaa tuntematonta ihmistä lähestymistestissä.

Tärkeimmät johtopäätökset olivat seuraavat: Vieroituksen jälkeistä hännänpurentaa on mahdollista vähentää lisäämällä vieroitusta edeltävää materiaalitarjontaa, mutta jatkotutkimuksia tarvitaan optimaalisten materiaalien laadusta ja vähimmäismäärästä. Vaaka-asentoisella tuoreella puuaineksella voi vähentää lihasikojen hännän- ja korvienpurentaa ja mahdollisesti myös stressiä, mutta jatkotutkimuksia tarvitaan puuesineiden optimaalisesta muodosta ja vähimmäismäärästä. Tuoreen puun läsnäolo karsinassa voi hiukan tehostaa pienistä olkimääristä saatavaa hyötyä. Alan tutkimusmenetelmien kannalta olennainen havainto oli myös se, että materiaalin tehoa hännänpurennan vähentämisessä ei voi ennustaa luotettavasti pelkän käyttöaktiivisuuden perusteella, koska muoviesineillä oli yhtä korkea käyttöaktiivisuus kuin puuesineillä mutta muoviesineet eivät vähentäneet hännän- ja korvienpurentaa.

Contents

List of original publications

This thesis is based on the following publications:

I Telkänranta, H., Swan, K., Hirvonen, H., Valros, A. 2014. Chewable materials before weaning reduce tail biting in growing pigs. *Applied Animal Behaviour Science* 157, 14–22, DOI: 10.1016/j.applanim.2014.01.004

II Telkänranta, H., Bracke, M. B. M., Valros, A. 2014. Fresh wood reduces tail and ear biting and increases exploratory behaviour in finishing pigs. *Applied Animal Behaviour Science* 161, 51–59, DOI: 10.1016/j.applanim.2014.09.007

III Pigs with but not without access to pieces of recently harvested wood show reduced pen-mate manipulation after a provision of feed and straw. *Applied Animal Behaviour Science,* submitted.

1. Introduction

Pigs are among the most numerous farmed animals worldwide (FAO, 2019). Nearly all pig farming in industrialised countries, and an increasing proportion of it in developing countries, is carried out intensively (FAO, 2019), which is driven by the demand for a low consumer price for pork, but has inadvertently caused substantial problems for animal welfare (rev. in Meunier-Salaun et al., 2007). One of the most severe welfare issues in intensive pig farming is tail biting, in which a pig injures, or in some cases amputates, the tail of another pig (rev. in D'Eath et al., 2014). Its aetiology is multifactorial, and one of the most important causes of tail biting is a scarcity of adequate materials for chewing and rooting (rev. in D'Eath et al., 2014).

In the European Union, the Council Directive 2008/120/EC states that "pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals" (European Union, 2008). However, in practice it is common for intensive farms to operate with a substantially lower level of materials provided, often relying on types of solid object that have no proven value in improving pig welfare and reducing tail biting (rev. in Buijs and Muns, 2019). In the USA, the provision of materials for manipulation for pigs is mainly limited to production involved in labelling schemes with animal welfare claims (rev. in van der Weerd et al., 2019). In China, a major pork-producing country, legislation and public awareness on animal welfare are limited and provisions of materials for pigs mainly absent (rev. in van der Weerd et al., 2019). One of the main reasons for the situation is that additional materials cause an increase in production costs. Other factors include, for example, lack of guidelines available to animal caretaker staff (Tarou and Bashaw, 2007; Peden et al., 2018) and scarcity of engagement of the financial sector with the issues (van der Weerd et al., 2019).

A growing body of research has shed light on the characteristics required of materials and objects to meet pigs' innate need for oral-nasal behaviours and to reduce tail biting and other harmful behaviours (reviewed in van de Weerd and Day, 2009; D'Eath et al., 2014; Godyn et al., 2019). In order to be adopted by the pig farming industry, it is also necessary for such materials and objects to be practicable and to improve pig health and production economy (van de Weerd at al., 2003). While the existing body of research has increased knowledge on the elements needed when developing solutions to the problem, there remains a need for further work on, for instance, how to simultaneously meet the criteria of attaining low material and labour costs; making the materials or objects sufficiently species-relevant to maintain pigs' active engagement for months; and reducing tail biting (rev. in van de Weerd and Ison, 2019). The aim of this thesis is to contribute to that avenue of research.

2. Review of the literature

A note on terminology: In scientific research, as well as among farmers, it is customary to refer to any supplementary substrates, objects, sounds etc. as “enrichment”. However, this may not be an optimal term for this purpose for two reasons. Firstly, it does not differentiate between addressing different functions, e.g. substrates for rooting or auditory stimuli. Secondly, it often appears to be perceived by farmers and the general public as a form of recreation instead of recognising that it involves the animals’ fundamental needs, which if left unmet can lead to severe health and welfare consequences. Therefore, in this thesis, substrates and objects added to pig pens will mainly be referred to as “materials for manipulation”, and, when specifically discussing objects but not substrates, “objects for manipulation”.

2.1 The role of behavioural needs in animal welfare

The relevance of the concept of animal welfare stems from evidence that all vertebrates, and some invertebrates, are sentient beings, i.e. capable of awareness and emotions (rev. in Broom, 2010). Definitions of welfare vary to some extent, but many animal welfare scientists consider an animal’s emotional state to be a core determinant (rev. in Weary et al., 2017).

One of the factors affecting an animal’s emotional state is the extent to which it can fulfil its behavioural needs (rev. in Broom, 2010). Behavioural needs are the subset of an animal’s behaviours that are innately motivated and intrinsically rewarded, and the need to carry out behaviours is present regardless of whether the behaviour is possible in the environment that the animal finds itself (rev. in Jensen and Toates, 1993; rev. in Broom, 2010). Living in an environment where behavioural needs are not met causes frustration and stress (rev. in Jensen and Toates, 1993). In domestic animals, despite their often greatly changed appearance as compared to their wild ancestors, behavioural needs have remained very similar to those of the wild ancestors: for instance, the domestic pig has retained most of the intrinsically motivated behaviours of the wild boar (Stolba and Wood-Gush, 1989). Behavioural needs have been studied, for example by measuring the motivational strength of animals for a particular behaviour, an approach that also makes it possible to investigate the relevance of different qualities and quantities of the environmental factors that provide an outlet for the behaviour (rev. in Jensen and Pedersen, 2008). Behavioural needs are sometimes referred to as “expressing natural behaviours” of the species. However, there is an important difference. It is not necessary or even beneficial for the welfare of an individual to carry out all the behaviours the species is capable of in the wild. Some, such as aggression, only belong to the behavioural repertoire of the species because they have enabled the wild ancestor to survive various emergency-type situations (rev. in Špinka, 2006). In addition to meeting behavioural needs, the prerequisites for good animal welfare include experiencing positive emotions, including those in which the animal has an active role in pursuing a goal, and having an ability to cope with physical and emotional challenges (rev. in Špinka, 2006; Korte et al., 2007). A fuller understanding of the factors affecting animal welfare, therefore, requires further research on not only animals' behavioural needs but also on their cognitive and emotional capacities, including how animals perceive their environment in farming settings (Nawroth et al., 2019).

2.2 Pigs' needs for rooting and chewing

Rooting and chewing are high behavioural priorities in pigs (rev. in Studnitz et al., 2007). Their role as genuine needs is supported by, for example, the finding that an insufficient availability of materials to root at and chew on causes more pessimistic responses in a judgment bias test (Douglas et al., 2012) and a blunted circadian rhythm of cortisol secretion (de Jong et al., 2000; Munsterhjelm et al., 2010), suggesting reduced welfare. As a social species, pigs often prefer to carry out oral-nasal behaviours in synchrony with their group mates, and the motivation for this is at its strongest at the pre-weaning age (Docking et al., 2008). The availability of suitable materials for manipulation and other characteristics of the physical environment during the first week of life also have consequences for the behavioural development of the piglets because the postnatal development of vertebrate brains has evolved to depend on particular environmental inputs, such as rewarding stimuli, novelty and complexity, during early ontogeny (rev. in Rodenburg, 2014; rev. in Telkänranta and Edwards, 2017). An example of long-term effects of early access to rootable and chewable materials is the finding that pigs reared in a pre-weaning environment containing straw and wood shavings showed fewer agonistic encounters at the age of three months than a control group (Munsterhjelm et al., 2009).

In order to meet the needs for rooting and chewing behaviours, a substrate or object must be capable of sustaining the pigs' interest over an extended time, not only during the first days when there is an additional attractive element of novelty. Results from preference tests and observational studies on pig behaviour have shown that the most suitable materials are complex in structure, can be moved and/or destroyed by the pig, contain sparsely distributed edible parts and are replaced by new materials at times (rev. in Studnitz et al., 2007). A systematic study comparing the effects of 74 objects showed that during the first day of exposure, the most attractive objects were those that were odorous, chewable, deformable, solid and not attached to pen structures; while on day 5, the most attractive objects were edible, destructible, solid or contained but not attached to pen structures (van de Weerd et al., 2003). A meta-analysis of 45 studies showed that bedding elicited the most interaction if it was present, and the absence of bedding increased interaction with objects; that suspended and deformable objects elicited more interaction than objects without these characteristics; and that providing a variety of objects increased total object interaction (Averos et al., 2010). Similarly, an expert panel of nine senior pig welfare experts, given a list of materials and objects to score, gave the best scores to the following materials and objects: long straw mixed with root vegetables, silage or feed; bales of straw; and straw mixed with bark or fresh branches; and the lowest scores to the following items: a mirror, a concrete block, a rubber mat, a minimal quantity of straw, a mineral block, a heavy plastic ball, a metal chain, a cross made of rubber hose, a car tyre and a bucket (Bracke et al., 2007). In addition to materials and designs of objects, effects on pig welfare also depend on the types of interaction pigs can have with the objects. For example, it is not known whether rooting and chewing are distinct needs. There is some evidence they may be interchangeable to some extent, as pigs prevented from rooting show an increase in other oral-nasal behaviours (Studnitz et al., 2003). However, other findings suggest different types of materials and objects fulfil different needs and cannot be used interchangeably (Bench and Gonyou, 2006). Quantity of material also affects what pigs can do with it. For instance, increasing the number of lengths of wood from two to four per pen increased the amount of activity directed to them (Larsen et al., 2019). Pigs are motivated to use materials synchronously, and if there is insufficient quantity for that, the pigs that fail to get access may redirect their oral-nasal behaviours at pen structures (Zwicker et al., 2015).

Of the materials generally available to farmers, straw appears to be best suited for improving pig welfare. In addition to being attractive for chewing and rooting in, it enables nest-building behaviour in preparturient sows, and straw bedding improves floor comfort and, during a cold season, also thermal comfort (rev. in Tuyttens, 2005; rev. in Vanheukelom et al., 2012). Pigs housed on straw may also have less gastric ulceration at slaughter than pigs without straw (Herskin et al., 2016) and straw helps stave off hunger between feedings (Douglas et al., 2015). Some other substrates, such as peat, have shown similar though lesser benefits (Vanheukelom et al., 2011). However, the widespread practice of using partially or fully slatted floors in pig pens causes severe practical limitations to the use of straw or other loose substrates in commercial pig farming, which has generated research on various single solid items, so-called point-source objects. For instance, in one study, pigs with combinations of objects such as hemp ropes and rubber balls showed less stereotypic behaviour and less redirected oral-nasal behaviours at each other than a control group (Casal-Plana et al., 2017). While straw remains the best option for pig welfare, it is feasible to design functional point-source objects that improve pig welfare to some extent, provided that the extensive existing knowledge on object characteristics to pigs is utilised in the design process (van de Weerd and Day, 2009).

2.3 Tail biting and other oral-nasal behaviours directed at pen-mates in intensive farming

Tail biting is one of the most severe animal welfare problems in intensive pig farming. In addition to the pain caused to the animals, it also affects production economics (Sinisalo et al., 2012). The pig is an omnivorous species and therefore more predisposed to development of abnormal, injurious oral behaviours than herbivores, but there also is individual variation in the propensity to develop such abnormal behaviours, due to genetic and neurobiological differences (Brunberg et al., 2011; rev. in Brunberg et al., 2016). Tail biting can be divided into three main types. “Two-stage” tail biting begins with mild chewing damage that increases in severity, and the main cause is probably a scarcity of chewable materials; in “sudden-forceful” tail biting, one of the causal factors is competition over insufficient resources; and in “obsessive” tail biting, the causal factors are not yet known (Taylor et al., 2010).

Tail biting is a multifactorial problem. Epidemiological studies on farms have suggested risk factors include poor air quality, poor health, insufficient quantity of food or water, as well as scarcity of substrates and objects to manipulate (Taylor et al., 2012), and high stocking density, insufficient number of feeder places causing competition and slatted or partially slatted floors that preclude the use of straw bedding (Moinard et al., 2003; Munsterhjelm et al., 2015). An increase in stocking density has been found to increase tail biting with a linear effect, while a decrease in feeder space increases tail biting with a quadratic effect (Laskoski et al., 2019). The causal mechanisms between stress and tail biting are not yet fully understood, and they are likely to be complex (rev. in Buijs and Muns, 2019). The role of stress as a causal factor is supported by the finding that in addition to cortisol data showing chronic stress in the bitten pigs, there also is evidence of elevated stress levels in the biters (Munsterhjelm et al., 2013). Furthermore, there is evidence suggesting effects of ambient temperature and season of the year (rev. in D’Eath et al., 2014). In contrast, some of the previously highlighted factors such as group size and nutritional value of feed appear to be of less relevance than believed earlier (rev. in D’Eath et al., 2014).

In many countries worldwide, the most common approach to preventing tail biting is tail docking, i.e. partially amputating the tails of young piglets, often without anaesthesia or analgesia (rev. in Nannoni et al., 2014). Docking can cause heightened sensitivity to pain in the stump of the tail (Di Giminiani et al., 2017), which is explained by the finding that injury to the nerves in the tail can result in development of traumatic neuromas, with the healing process remaining incomplete for months after docking (Sandercock et al., 2016).

Ear biting is a similar problem to tail biting, but considerably less studied. At least some of the risk factors are the same, such as competition over feeding places, scarcity of substrates to manipulate and overall hygiene (Smulders et al., 2008). As with tail biting, ear biting appears to be an umbrella term for a group of behaviours with a different motivational origin, ranging from gentle manipulation to quick bites (Diana et al., 2019).

In intensive farming, it is also common that even when there is no visible tail or ear damage, pigs direct rooting and chewing behaviours at other pigs (rev. in Studnitz et al., 2007). One of the main causes is scarcity of substrates to root at and chew on; for instance, when provisions of straw are small, the frequency of pen-mate manipulation has a linear negative correlation with the quantity of straw (Pedersen et al., 2014). In addition to rooting and chewing, some other behaviours may also form the motivational basis for the oral-nasal contacts observed in studies. Tail-in-mouth behaviour involves one pig gently taking the tail of another pig into its own mouth, without the target pig attempting to escape; it is considered a normal social behaviour in pigs, as it has sometimes been observed in semi-natural environments (rev. in Schrøder-Petersen et al., 2004). It is also possible, though as yet insufficiently studied, that oral-nasal manipulation of other pigs in intensive farming may also, in some situations, constitute redirected manipulation of nest materials because constructing nests for sleeping and rearranging nest materials before settling to sleep is part of the behavioural repertoire of the wild boar (rev. in Mayer et al., 2002) and it has also been observed in domestic pigs in semi-natural conditions (Stolba and Wood-Gush, 1989).

2.4 Effects of material availability on tail biting and other oral-nasal behaviours directed at pen-mates

Efficacy of different materials and object designs in reducing harmful behaviours vary substantially. In a literature review on effects on tail and ear biting, aggression, other harmful social behaviours, fearfulness, play behaviour, health and hygiene, the tentative conclusion was that straw and compound materials are the most beneficial; that objects of rubber, rope and wood as well as substrates and roughage feed may be sufficient; and that metal objects are not suitable for pigs (Bracke et al., 2006). In a study comparing the efficacy of various materials on preventing tail biting in a situation where it has not yet occurred vs. as an intervention to stop ongoing tail biting, straw on the floor was more efficient than metal chain and rubber hose in both functions: as a prevention and as an intervention. Furthermore, some treatments were found to be efficient only when used as prevention, but not when used as an intervention to stop tail biting that had already started. Of such preventive measures, straw provided in a metal rack on a pen wall was less effective than straw on the floor, but more effective than the metal and rubber objects. By contrast, as an intervention to tail biting once it had already started, straw racks were no more effective than the metal and rubber effects (Zonderland et al., 2008). In another study comparing interventions at the point of noticing the first symptoms of a tail-biting outbreak, straw was found to be more efficient than rope, which in turn was more efficient than no intervention (Lahrmann et al., 2018). Furthermore, the beneficial effects of some combinations of different materials can be additive (Guy et al., 2013). There also are commercially available objects that are intended to reduce tail biting, such as Bite-Rite chewing sticks of soft plastic. However, there is little evidence of their actual efficacy. In studies comparing Bite-Rite to straw and a dispenser providing flavoured feed (van de Weerd et al., 2006) and to straw and rope (Lahrmann et al., 2019), Bite-Rite had the lowest efficacy of the materials tested in reducing tail biting.

Although straw has substantial capacity to reduce tail biting and improve pig welfare, a crucial factor determining its efficacy is the quantity of straw provided. A behavioural study aimed at determining the threshold after which adding more straw no longer increased straw-directed behaviours in pigs found the threshold to be approximately 250g of straw per pig per day (Jensen et al., 2015). However, a larger quantity of straw, approximately 360g per pig per day, is needed to reach the threshold after which a further increase in straw quantity no longer promotes a further decrease in redirecting oral-nasal manipulation at pen-mates (Pedersen et al., 2015). At lower quantities of straw, the efficacy in meeting pigs' needs is diminished: 150 g per pig per day is less efficient at preventing tail biting than is tail docking (Larsen et al., 2018), and no differences in oral-nasal behaviours targeted at other pigs were found in a study comparing provisions of 25, 50, and 100g per pig per day (Oxholm et al., 2014). Changes in straw quantity do affect behaviour:

moving pigs from an environment with straw to an environment without straw increases adverse behaviours in other pigs, while the beneficial effects of straw are enhanced if the pigs also have prior experience of straw (Day et al., 2002). Studies comparing long vs. chopped straw have resulted in partially inconclusive findings. While access to chopped straw is better for welfare than no access to straw, it also is more difficult for pigs to manipulate than long straw and may thus not reduce adverse behaviour towards other pigs (Day et al., 2008) despite pigs spending a similar total amount of time engaging with long vs. chopped straw (Lahrmann et al., 2014). The way of presenting the straw also has an effect. Loose straw on the floor is preferred to straw provided in a metal rack, which in turn is preferred to a solid straw block (Zwicker et al., 2013), and some straw dispensers are rather inefficient in engaging pigs (Bulens et al., 2015).

On most pig farms, pen floors are partly or fully slatted and manure is managed as slurry, with the consequence that many farmers only use straw in very small quantities or not at all to avoid blockage of the drainpipes (rev. in Buijs and Muns, 2019). Instead, various solid objects are used on many farms. There is a discrepancy between the types of object most commonly used on farms, such as metal chains and plastic objects, vs. the types of objects that in experimental studies have proven most effective in reducing tail biting and other harmful behaviours (rev. in Buijs and Muns, 2019). This may be linked to the finding that the views of farmers and scientists also differ on the most important risk factors for tail biting (Valros et al., 2016). In general, there has been limited information exchange between the farming community and scientific community, which may be one reason why some farms still use objects that are insufficient in quantity and inefficient in their ability to maintain pigs' interest (rev. in van de Weerd and Ison, 2019). At the same time, further research is needed to better understand which characteristics of materials, object designs and quantities are most efficient in reducing harmful behaviours, as well as to better understand the causal mechanisms underlying such effects. The need for further research is illustrated by the finding that not only do the views of scientists often differ from those of farmers, but views of different experts sometimes do so as well (rev. in Buijs and Muns, 2019).

Several characteristics of objects influence their ability to maintain the interest of pigs and to reduce redirection of oral-nasal behaviours at other pigs. In an experimental study testing 74 objects and substrates, including e.g. different types of chains, balls, canisters, plastic pipes, sisal ropes, rubber boots and edible root vegetables, van de Weerd et al. (2003) found the characteristics "ingestible", "odorous", "chewable", "deformable" and "destructible" to be associated with high object interaction. The five objects or substrates that elicited the most interaction on day 1 were, in descending order: lavender straw with whole peanuts in a box; a basket made of maize; a burlap (also known as hessian or jute) sack in a box; suspended coconut halves; and suspended string. The five objects that elicited the most interaction on day 5 were, in descending order: lavender straw with whole peanuts in a box; suspended carrots; suspended coconut halves; long straw in a box; and swedes in a box (van de Weerd et al., 2003). A meta-analysis by Averós et al. (2010) found that objects' characteristics eliciting the most interaction were the object being deformable and suspended at eye or floor level.

While access to even a small number objects elicits activity (rev. in Godyn et al., 2019), and while even a small change in the available amount causes measurable behavioural changes (Spoolder and Bracke, 2008) and may improve pigs' cognitive and physiological development (Tönepöhl et al., 2012), reduction in tail biting represents a more challenging goal. There are partially contrasting findings on which objects are most beneficial in reducing tail biting, probably because behavioural benefits depend not only on the material the objects are made of, but also on object design, location in pen and potentially other factors. There is evidence of a beneficial interaction effect of bedding and object availability; of simultaneous availability of different types of object; and a preference for deformable and suspended objects (rev. in Averos et al., 2010). Novelty is another important characteristic. Novelty of an object can sometimes override characteristics that are otherwise relevant to pigs, such as object cleanliness (Beaudoin et al., 2019). However, the efficacy of a novel object in reducing biting of other pigs vanishes rapidly as the object becomes familiar (van de Perre et al., 2011). Regaining of the novelty effect requires an absence of the object for a minimum of five days and possibly longer (Gifford et al., 2006). A further factor, as yet insufficiently studied, is early-life experience. Most studies on tail biting have been carried out on pigs at an age when tail biting does occur, especially on growing and finishing pigs. However, causal factors of tail biting may partially originate from the pre-weaning environment (rev. in Barnett et al., 2001; rev. in Telkänranta and Edwards, 2017).

In addition to investigating effects on tail biting, the most commonly recorded parameters in studies involving various solid objects have been the frequency of interaction with the objects and the frequency of oral-nasal manipulation of other pigs (rev. in van de Weerd and Day, 2009). The rationale for measuring object interaction is based on the assumption that increased interaction shows that pigs are better able to perform oral-nasal activities such as rooting, which are high behavioural priorities in pigs (rev. in Studnitz et al., 2007) and/or that higher activity reflects better welfare, as inactivity is in some cases a symptom of depression-like states (rev. in Fureix and Meagher, 2015). The rationale for measuring oral-nasal manipulation is the assumption that it reflects redirecting of oral-nasal behaviours at other pigs and therefore increases risk for tail biting (rev. in Godyn et al., 2019). Other parameters measured, though in a limited number of studies, include growth in the form of daily weight gain, which in most studies has not been affected by objects but in a few studies has been improved by access to rope, rubber tyres or a wooden log; plasma cortisol, which has not been influenced by access to rope, cloth, rubber tyres or metal objects; and the latency to approach a human in the home pen, to which access to ropes and rubber tyre tubes has been found to have a reducing effect (rev. in van de Weerd and Day, 2009). An example of behavioural parameters that have not been studied in the context of objects for pigs is whether the materials and/or locations of objects affect pigs' selection of defecation sites. This may affect the level of soiling of the solid floor, which in turn can affect the cleanliness of objects, a relevant characteristic for pigs (Bracke, 2007).

To better understand which types of object could best reduce tail biting and other harmful behaviours, several questions require further study. One of them concerns the use of different types of wood. In some studies, wooden objects have had no discernible effects (Fabréga et al.,

2019) while in others, they have reduced tail biting (Cornale et al., 2015), and behavioural differences have been associated with different species of tree (Chou et al., 2018). A likely major reason is that the types of wood used in the studies have ranged from recently harvested and still odorous wood to commercially processed dry timber (red. in Buijs et al., 2019). Additional questions that require further study concern the use of plastic and metal objects. They are among the most commonly used object materials in commercial farming (rev. in Buijs and Muns, 2019). However, in an experimental study by van de Weerd et al. (2003), a total of 19 of the 74 objects tested were made of plastic, but only one of them (a plastic string) was among the ten most efficient objects in eliciting interaction, either on Day 1 or Day 5 of the experiment. As for metal, there is a general consensus among scientists studying pig behaviour that metal objects are not sufficient for pigs (Bracke et al., 2006), but there also are some indications that presenting metal chains in a branching design, in which there are several vertically hanging arms of the chain, including at least one that reaches the floor, may elicit more interaction than single chains (Bracke and Koene, 2019).

There also is a need for further research on parameters relevant to feasibility and economics of use on commercial farms as these are among the major factors affecting whether or not the objects recommended by scientists become adopted in commercial situations (van de Weerd and Ison, 2019). There is little knowledge on the effects of various objects on mortality and pig health (van de Weerd, 2009). Furthermore, in studies investigating the effects of various objects on pig behaviour, calculations on material and labour costs of the objects are normally not reported, although they are of major significance to farmers (van de Weerd and Ison, 2019).

3. Aims

The main aim of the four studies presented in this thesis was to investigate the efficacy of selected objects, with attention to both their materials and designs, in reducing tail-biting damage in commercially farmed pigs. The objects were intended for use as additions to the provision of a minimal amount of optimal material defined in the EU Council Directive 2008/120/EC. For practical relevance in intensive commercial farming, the selection criteria for the materials and designs of the objects included compatibility with slatted floors and management of manure as slurry, which are common features in intensive pig farming. The other aims of the studies were to investigate the effects of the selected materials and object designs on ear-biting damage; on the frequency of redirecting oral-nasal behaviours at other pigs; on the frequency of engaging with the materials provided; and on outcomes relevant to production, such as mortality and pen hygiene. Additionally, tentative calculations were carried out on the costs of materials and labour as compared to the efficacy in reducing tail biting. All the work focussed on determining the effect of the objects on intact i.e. undocked tails, because there already is an extensive body of research on effects on docked tails but less research has been done in pigs with intact tails, despite the fact that one of the aims of research in developing such objects and of the abovementioned EU Council Directive is to attain a future in which tail docking is no longer needed, i.e. pigs with intact tails are the ultimate target population in which such objects should function well.

In the below, the studies in publications I, II and III, on which this thesis is based, are referred to with their Roman numerals as Study I, Study II and Study III, respectively. Additionally, this thesis contains results based on an unpublished study, which is referred to as Study IV.

In Study I, the main research question was whether pre-weaning exposure to sisal ropes and paper would reduce post-weaning tail biting. In Studies II, III and IV, the main research questions were whether providing growing-finishing pigs and breeder gilts with objects made of recently harvested wood (instead of commercially dried timber that is usually used in wooden objects for pigs) would reduce tail biting; and whether the same effect could be attained with metal and plastic objects with moderately added complexity.

In Study I, we hypothesised that (a) an experimental group with access to the supplementary experimental materials from birth to weaning would show more oral-nasal manipulation of materials and less oral-nasal manipulation of other piglets than a control group with access to materials of lower quality and quantity, (b) the effects of the experimental treatment on pre-weaning growth and mortality would be either neutral or beneficial, and (c) after transferring the piglets to a post-weaning environment identical to that of the control group, the above differences in oral-nasal behaviour would persist and the experimental group would accumulate less post-weaning tail-biting damage than the control group.

In Study II, we hypothesised that (a) after 2.5 months of continuous exposure to supplementary experimental objects of metal, plastic and recently harvested wood, finishing pigs would still show more oral-nasal manipulation of objects and less oral-nasal manipulation of other pigs than the control group, (b) pigs with added objects would have less tail and ear-biting damage than the control group, (c) the effects of the supplementary objects on pen hygiene and the number of pigs transferred to hospital pens would be either neutral or beneficial, where the rationale for the former was to investigate potential effects on health, and for the latter, potential effects on selection of defecation sites, both of which have received little research attention, and (d) the magnitude of the beneficial impacts above would differ according to the materials used in the objects, with metal providing the lowest benefits, plastic providing intermediate benefits and wood providing the highest benefits, and with a treatment combining all three materials providing higher benefits than any one of them alone.

In Study III, we hypothesised that (a) after two months of continuous exposure to experimental objects of recently harvested wood, breeder gilts would still show more oral-nasal manipulation of objects and less oral-nasal manipulation of other gilts than the control group that had equally long exposure to objects of commercially sourced wood and complex metal chain, (b) the above difference would be seen both before and after a daily provision of long straw, (c) gilts with the experimental objects would have less tail and ear biting damage than the control group, (d) gilts with the experimental objects would show a lower latency to approach an unfamiliar human than the control group, and (e) the effects of the experimental objects on the percentage of the gilts approved as future breeders would be either neutral or beneficial, which has not specifically been studied before, but the prediction was based on an assumption of overall health being either not affected by the experimental objects or being improved if the experimental objects helped reduce stress.

In Study IV, we hypothesised that (a) after four months of continuous exposure to supplementary experimental objects of recently harvested wood or polythene plastic, pigs would have less tail and ear-biting damage than a control group without such objects, (b) pigs with the experimental objects would show a lower latency to approach an unfamiliar human than the control group, and (c) the magnitude of the beneficial impacts above would differ according to the materials used in the experimental objects, with wood providing higher benefits than plastic.

4. Materials and methods

4.1 Pilot experiments leading to the current studies

In order to successfully reduce tail biting in commercial pig farming, the following criteria were used in selecting materials and object designs for testing, observing the recommendations of van de Weerd and Day (2009): (i) compatibility with partly slatted floors and with the management of manure as slurry, i.e. avoiding the risk of blocking the drain with loose parts; (ii) low material and labour costs incurred by constructing, attaching and removing the objects or in distributing loose materials; (iii) safety to the animals and farm staff, i.e. no hazardous component chemicals, sharp edges or risks to become entangled in ropes or chains; (iv) hygiene, i.e. attaching the objects to pen structures so that they do not become soiled by faeces, and selecting the locations of the objects in pens so that they do not alter the pigs' perception of the toilet area in a way that leads to increased faeces or urine on the solid part of the floor; and (v) evidence of ability to sustain pigs' interest for a prolonged time.

Two pilot phases were carried out before the studies on which this thesis is based: a small-scale pilot before Study I and another pilot before Studies II–IV. The aim of the pilot studies was to determine which materials, quantities, object designs and object locations to use. Most of the object designs used in Studies I–IV (i.e., object shapes, sizes, methods of suspension and locations in pens) were developed during these pilot phases. While the pilot results were useful for planning the full-scale studies, it is important to bear in mind that these are unpublished results based on small sample sizes and short periods of observation, and all of them warrant further larger-scale study.

The first pilot phase, prior to Study I, supported our hypothesis that piglets started interacting with paper and sisal ropes during the first week of life, supporting a decision to provide them from birth. The pilot also showed that in a minority of the crated sows, the experience of piglets in the same pen receiving paper, i.e. high-value novel material, that was out of the reach of the sow, elicited such intensive attempts by the sows to access the paper that some sows risked injury when trying to break out of the crate. These risky behaviours disappeared when the experimental practice was changed to providing each sow in the experimental group with a sheet of paper at the same time as distributing sheets of paper to piglets. The pilot phase also showed that suspending sisal ropes adjacent to the solid heated creep area and part of the slatted floor area did not trigger any defecating behaviour in these areas. However, due to hygiene concerns of the farmer, the length of the ropes was kept short enough to ensure that the ends of the ropes did not touch the floor.

The second pilot phase, prior to Studies II–IV, supported our hypothesis that the frequency of interaction with wooden logs depended to a large extent on whether they were fixed or allowed some movement, the movable logs being more attractive. Another factor that appeared to affect attraction was the position in which they were attached in the pens. In the following, the positions tested are listed in an order of decreasing frequency of manipulation at a point in time when the objects had been in place for two weeks: on the floor (although this was left out of the study due to hygiene concerns of the farmers); in a horizontal position below snout level; in a horizontal position at snout level; at a 45-degree angle; and in a vertical position. Wood from four species of tree was tested in a preference test in the pilot: birch (*Betula pendula* and *Betula pubescens*), alder (*Alnus incana* and *Alnus glutinosa*), aspen (*Populus tremula*) and Scots pine (*Pinus sylvestris*). Assessing the number of tooth marks accumulated in two weeks showed substantial chewing at each type of wood, but the extent of chewing was approximately twofold in birch as compared to each of the other species, so it was selected for the study. Other plant-based materials tested in the pilot phase were commercially available compressed peat plates for suckling piglets and finishing pigs, as well as toilet paper for suckling piglets, with the rationale of it being a material that dissolves in manure without blocking the drain. These two materials were not selected to be used in the studies because the pilot phase showed that the peat plates were too hard to be of substantial interest to suckling piglets, were consumed too fast by finishing pigs if placed on the floor, and were too difficult to access for finishing pigs if placed in a straw rack; and because toilet paper was eaten, causing concerns of intestinal blockage if used in large quantities. Sisal rope was also tried during the pilot phase for each of the age groups but deemed suitable only for suckling piglets. A low-cost device for weaned piglets and growing-finishing pigs was designed for delivering rope only 5cm at a time, to prevent issues of long fibres getting bitten loose and falling through the slatted floor and disrupting the functioning of manure pumps. However, because sisal rope has a higher cost than the other materials tested and the pigs' consumption of it was considerable (the exception being suckling piglets, as they did not yet have enough bite force to cut the fibres in rope), its estimated cost of use per pig per day was several times that of the other materials, impacting its feasibility on commercial farms with pigs past weaning age.

Of the non-plant-based materials in the pilot phase before Studies II, metal chain and plastic pipes made of medium-density polythene were tested, because they are used in many commercial farms, are of low cost and are generally considered safe. Medium-density polythene pipes are used e.g. for piping drinking water for human consumption and chewing on them causes them to change shape rather than break into small particles. The safety of metal chains, however, may not be as unambiguous as generally assumed: there is anecdotal concern among veterinarians that frequent chewing of metal chains may cause wear on tooth enamel and breaking of teeth. In the pilot phase, the main question regarding plastic pipes and metal chains was whether constructing objects with increased complexity would increase the ability of these materials to keep the pigs occupied for months, not just for the initial days when novelty increases their attractiveness, and therefore potentially yield welfare benefits. With plastic pipes, the two most promising designs of those tested in the pilot were the "helicopter" design, i.e. horizontal cross that is used on some commercial farms, at least in Western Europe, and a design similar to that with the wooden logs above; these designs were then used in Studies II and IV, respectively. For branching chains, pigs showed a slightly higher frequency of object interaction with long-link metal chain made of 4mm thick wire, as compared to short-link chain and higher thicknesses, based on behavioural observation at a point in time when the chains had been in the pens for two weeks. The chain design that was then tested in Study II, the branching chain, had been developed by one of the co-authors, and it had earlier elicited sustained interest in organic pigs on solid floors (Bracke, pers. comm.), so it was tested in the pilot phase of these studies as well. There was some evidence that plastic and metal objects may have a different effects than wooden objects on finishing pigs' defecating behaviour: one of the outcomes of the pilot was that when objects were attached to the pen wall adjacent to a solid floor, manure and urine started accumulating next to the objects in some of the pens with plastic or metal objects but none of the pens with wooden objects. When the objects were attached to the pen wall adjacent to slatted floor, in some of the pens with wooden objects the outcome was an increase of faeces and urine on the solid part of the floor, suggesting wooden objects may have some significance that plastic and metal objects do not, in relation to how pigs use different areas for different activities. Whether this also occurs in more extensive studies specifically designed to test this effect, requires further investigation; but due to farmer concerns, this pilot finding was used as a basis for selecting the locations for objects in the Studies II–IV below. The problem of soiling did not occur in the trials on organic farms (Bracke, M., pers. comm.), which may suggest that in different environments pigs perceive some objects and/or materials in different ways. If it indeed is the case that some object designs that work well in an organic setting may not be as functional in barren commercial pens, then this further emphasizes the need to investigate new solutions for materials and objects to improve pig welfare in intensive farming.

4.2 Animals, housing and management

This thesis is based on four experimental studies, each of which was carried out on a different commercial pig farm in Finland. In this thesis, the farms will be referred to as Farm I, Farm II, Farm III and Farm IV, according to the number of the publication, manuscript or dataset originating from that farm.

The data presented in this thesis represent a total of 2064 pigs. Details on the types, ages, breeds and numbers of pigs are shown in Table 1. None of the pigs were tail docked – tail docking is banned in Finland (Finland's Ministry of Justice, 2002). All the male pigs had been surgically castrated at the age of five to seven days.

Table 1. *The pigs included in the four studies.*

Farm number	Types of pig	Age of pigs at the beginning and end of study	Breeds of which the pigs were crossbreeds	Number of pigs in the study
I	Piglets	From birth to 2 months	50% Norwegian Landrace, 50% Yorkshire	438
II	Growing-finishing pigs	From 2 to 5 months	50% Norwegian Landrace, 25% Yorkshire, 25% Duroc	803
III	Breeder gilts	From 2 to 6 months	50% Norwegian Landrace, 50% Yorkshire	167
IV	Growing-finishing pigs	From 2 to 6 months	50% Norwegian Landrace, 25% Yorkshire, 25% Hampshire	656

All the farms had partly slatted floors, indoor housing only, and mechanical ventilation. Feeding was carried out in the form of liquid feed, i.e. a meal-water mixture delivered at set times of the day, except for piglets of pre-weaning age. Water was provided via nipple drinkers.

Farm I was a piglet-producing farm, on which the sows farrowed in crates and were kept crated during the entire lactation. The floor area in each farrowing pen, including the area covered by the crate, was 2m x 2.5m. Of the pen floor inside the crate, the front half was made of slatted metal, and the rear half was made of solid concrete. Outside the crate, the pen floor was plastic-covered slatted floor, with a solid heated creep area for the piglets, measuring 0.4m x 1m, with no shelter. There was one infrared heat lamp above each creep, switched off once the piglets reached approximately one week of age. Commercial dry piglet feed was provided in a bowl from Day 4 onwards. The piglets were weaned at the age of 21 to 25 days and transferred to growing pens, mixing two litters per pen and without separating males from females. The floor area of each growing pen was 2m x 4m, half of which was solid concrete floor and the other half was slatted metal floor. The average group size was 18 piglets/pen, resulting in an average floor area of 0.4m^2/piglet.

Farm II was a finishing farm, to which pigs were bought at the age of two months and sent to slaughter at the age of five to six months. Males and females were kept as mixed groups in each pen. The floor area in each pen was 2m x 4m, of which 75% was solid floor and 25% was slatted floor. The average group size was 11 pigs/pen, resulting in an average floor area of 0.7m^2/pig. This space allowance is below the minimum set by the current Finnish legislation (Finland's Ministry of Justice 2017), but the experiments on this farm were carried out before the legislation was changed to its current form.

Farm III was a piglet-producing farm that also reared its breeder gilts; on this farm, the focus of the study was on the gilts. They had been born in pens with farrowing crates and no bedding, weaned at the age of three to four weeks and transferred to weaner pens without mixing litters. The pigs were transferred from weaner pens to gilt pens at the age of two months, again without mixing litters. The floor area in the gilt pens, in which the study was carried out, was 3m x 4m, of which 60% was solid floor and 40% was slatted floor. The average group size was seven pigs/pen, resulting in an average floor area of 1.7m^2/pig.

Farm IV was a combined piglet producing and finishing farm; on this farm, the focus of the study was on the finishing pigs. They had been born in pens with farrowing crates and no litter, weaned at the age of three to four weeks and transferred to weaner pens, sorting males and females to different weaner pens, and mixing piglets from four litters in each pen. At the age of two months, the piglets were transferred to finishing pens. The floor area in the finishing pens, in which the study was carried out, was 3m x 5m, of which 75% was solid floor and 25% was slatted floor. The average group size was 15 pigs/pen, resulting in an average floor area of 1.0m^2/pig.

All experimental procedures in these studies had been granted an ethical approval by the Ethics Board of Viikki Campus of the University of Helsinki. All the management practices on the farms represented ordinary commercial practices on those farms. An animal experiment licence was not required as the experiments did not cause any pain or harm to the animals.

4.3 Treatments and experimental design

The experimental unit in each of the studies was a pen. The pens were allocated to treatments described below, balancing the ages and locations of pens across treatments. In all the studies, the control treatment represented the types, quantities and locations of objects and substrates that were normally provided on that farm, and experimental treatments represented objects and/or substrates that were selected by us.

In those control treatments that included the use of wood shavings, these were a mixture of European spruce, *Picea abies* and Scots pine, *Pinus sylvestris.* In those experimental treatments that included the use of recently harvested wood, the wooden objects were made of birch, *Betula pendula* and *Betula pubescens*, harvested less than two months before the pigs first came into contact with them. They had been stored indoors, had not undergone any commercial drying processes, and the bark had not been removed. In those experimental treatments that included the use of plastic pipes, they were made of medium-density polythene, with a diameter of 5cm.

All the objects, both control and experimental, were attached in the pens before the pigs were brought into the pens. All the objects remained in place throughout the duration of the studies and until the pigs left the pens. No maintenance, repair or replacement of objects was carried out during the studies.

4.3.1 Study I

Five batches of piglets were used, with a batch defined as piglets housed in the same room of farrowing pens at the same time. The numbers of pens in the experimental vs. control treatments were balanced across batches. A total of 59 farrowing pens were allocated to two treatments: 30 pens in an experimental treatment and 29 pens in a control treatment. There were originally 30 pens in each treatment, but one of the sows in the control treatment died a week after birth because of pre-existing health issues not detected when selecting clinically healthy sows for the study.

In the control treatment, each pen was furnished with one Anti-Bite ball (Albert KerblGmbH, Germany), made of hard plastic, suspended on a metal chain near a pen corner on the pen wall adjacent to the heated creep area. Wood shavings were provided twice a day, in the morning and afternoon, approximately one handful per pen at a time.

In the experimental treatment, each pen was equipped with the above and with ten lengths of sisal rope (Piippo Oy, Finland) of diameter 1cm and length approximately 1.3m, suspended from the midpoint to provide ten pairs of ropes that were spaced approximately equidistantly along the pen wall adjacent to the heated creep area. This way, the ends of the pairs of ropes were approximately 5cm above the pen floor. Additionally, sheets of newspaper (non-glossy, with no staples or other non-paper parts) with dimensions of 60cm x 84cm were distributed twice a day, in the morning and afternoon but as separate events from the distribution of wood shavings. For piglets under two weeks of age, the quantity was one sheet at a time, and for piglets from the age of two weeks onwards, two sheets at a time. In order to prevent frustration in the crated sows unable to reach the paper given to their piglets, each sow in the experimental treatment was also given one sheet of newspaper, placed inside the crate in front of the sow at the same time as paper was distributed to the piglets.

The continuously available objects, i.e. the plastic balls and ropes, were placed in the pens before the piglets were born and remained in place until weaning. At weaning, the piglets were transferred to growing pens, mixing two litters in each growing pen so that litters in the same pen came from the same treatment. All growing pens were furnished identically for both treatments: in the middle of each pen, there were three double lengths of sisal rope (effectively six ropes) suspended from a horizontal board, which in turn was suspended from the ceiling, and on a wall of each pen there was a Bite-Rite chewing stick (Ikadan, Denmark) made of soft plastic, attached in a horizontal position. Wood shavings were distributed on the solid floor twice a day, approximately 2–3L at a time.

During the post-weaning period, the farm experienced a few episodes of feeder equipment malfunction. As a consequence, the weaned piglets of one of the batches experienced one day without feed, and the weaned piglets in another batch experienced two non-consecutive days without feed. This accidental stressor was incorporated in the analysis of data.

4.3.2 Study II

Five batches of pigs were used, with a batch defined as pigs housed in the same room at the same time. The numbers of pens in the experimental vs. control treatments were balanced across batches. A total of 73 finishing pens were allocated to five treatments: 14 pens with wooden objects (W), 13 pens with plastic objects (P), 15 pens with branching metal chains (B), 14 pens with all of the above objects (WPB) and 17 control pens (C). The original experimental design involved 16 pens in each treatment, but the farm staff had furnished one of the W pens as a C pen in error, and the farmer converted some of the other pens to hospital pens due to shortage of hospital pen space.

In the control treatment, each pen was furnished with a straw rack, filled with long straw whenever empty, attached on a pen wall over the solid floor area; and with a 5mm thick metal chain suspended on a pen over the slatted floor area. Wood shavings were distributed on the solid floor once a day, approximately 300g at a time.

The pens in four experimental treatments were furnished with chains, straw racks and wood shavings identical to the control treatment, as well as additional objects as follows: in the W treatment, the objects were pieces of wooden logs with a diameter varying between 10cm and 15cm. In each pen, one log with a length of 100cm and six logs with lengths of 40cm: each were suspended on metal chains on the pen walls above the solid floor area. The logs were in a horizontal position and below snout level, at a height of approximately 10 to 40cm above the floor. Each 100cm log was suspended by two metal chains attached near each end of the log. The 40cm logs were suspended as pairs, attaching the metal chain at the midpoint of each log. In the P treatment, the objects were made of plastic pipes with a length of 60cm. For each pen, two such pieces of pipe were attached at the middle to form a cross, which was then suspended from the ceiling over the slatted floor area in a horizontal position at snout height. In the B treatment, the objects were made of 4mm thick metal chain. For each object, a 120cm chain and a 70cm chain were attached to each other to form an asymmetrical cross. The point of attachment was at the distance of 40cm from one end of each chain. In each pen, two such crosses were suspended on the pen wall above the slatted floor, at approximately 1m from each other. Each cross was suspended by one of the short (40cm) arms, so that the end of the longest hanging arm reached the floor and the two other hanging arms were at different heights above the floor and below snout level. In the WPB treatment, each pen contained all three types of supplementary object, in the same quantities and locations as described above.

4.3.3 Study III

All the pigs in this study were present in the same room at the same time, constituting one batch. A total of 24 pens were allocated to two treatments: 12 pens in an experimental treatment and 12 pens in a control treatment. In both treatments, l-Long straw was distributed on the solid floor once a day, approximately 150g per pen.

In the control treatment, each pen was furnished with one piece of wooden board of Norway spruce, *Picea abies,* sourced commercially, with dimensions of 2cm x 10cm x 40cm, suspended by a metal chain below snout height in a pen corner above the slatted floor area; and with a 60cm length of feeder chain made of metal, suspended in a vertical position in the other pen corner above the slatted floor area.

In the experimental treatment, the objects described above were not present, and the only objects available were the experimental objects. These were pieces of wooden log, with the diameter ranging from 5cm to 7cm. In each pen, one 80cm long log was suspended on the pen wall by two metal chains, attached near each end of the log, above the solid floor area in a horizontal position below snout level. Two 40cm long logs were suspended by metal chains, each in a separate corner above the slatted floor area, in a horizontal position below snout level.

4.3.4 Study IV

In Study IV, four batches of pigs were used, with a batch defined as pigs housed in the same room at the same time. The numbers of pens in the experimental vs. control treatments were balanced across batches. A total of 44 pens were allocated to three treatments: 16 pens with wooden objects (W), 12 pens with plastic objects (P) and 16 control pens (C). The original experimental design involved 16 pens in each treatment, but the farm staff had a shortage of pigs and had decided to furnish only 12 pens as P pens.

In the control treatment, each pen was furnished with a straw rack, filled with long straw whenever empty, attached on a pen wall over the solid floor area.

The pens in two experimental treatments were furnished with straw racks identical to those in the control treatment, as well as additional objects as follows: in the W treatment, the objects were pieces of wooden log, with the diameter ranging from 5cm to 7cm. In each pen, four 40cm long logs were suspended on metal chains, two logs per chain, below the straw rack above the solid floor area. The logs were in a horizontal position at approximately snout level. In the P treatment, the objects were made of a 100cm long plastic pipe that was suspended by metal chains in a horizontal position at snout height on the pen wall above the slatted floor area, and four 20cm pipes that were attached at each end of the 100cm pipe, two 20cm pipes at each end; each of these shorter pipes was suspended from one end, hanging in a vertical position. There was one deviation from this design: in the experimental treatment, the farm workers had accidentally placed some of the wooden objects above the slatted floor area instead of above the solid floor as instructed.

4.4 Data collection

4.4.1 Tail damage (I, II, III, IV)

In Study I, tail damage was assessed at the age of eight weeks by examining each pig's tail visually and by palpating the entire length of the tail. The scale and definitions used were the same as those used by Kritas and Morrison (2004), in which the definitions are as follows: 0 = no evidence of tail biting; 1 = healed or mild lesions; 2 = evidence of chewing or puncture wounds, no swelling; 3 = evidence of chewing or puncture wounds with swelling and signs of infection; 4 = partial or total loss of the tail. Healed or mild lesions were defined as healed skin with wounds no longer bleeding but with the skin not yet healed, or as superficial lesions that did not involve a cut through the epidermis. Evidence of chewing was defined as lesions involving current or earlier bleeding. Swelling and signs of infection were defined as an abnormal bulging in the outline of the tail, detectable by visual inspection and/or palpation, including those cases where new skin had grown over the lesion, but the underlying swelling remained.

In Study II, tail damage was assessed at the age of 4.5 months by examining each pig's tail visually. The scale and definitions used were developed during a pilot phase of this study, as follows: 0 = an undamaged tail; 1 = tail-end hairs missing and/or blood on the tail; 2 = part of the tail missing, with more than 5cm remaining; 3 = part of the tail missing, with less than 5cm remaining. Missing parts of tails were defined by comparing the length of the tail with that of an undamaged pig.

In Studies III and IV, tail damage was assessed at the age of four months (Study III) or six months (Study IV) by examining each pig's tail visually. The scale and definitions used were developed during a pilot phase of Study III, as follows: no damage = an intact and entire tail. Mild damage = scratches, wounds or scars. Severe damage = part of tail missing. Scratches were defined as superficial lesions with no bleeding, wounds were defined as involving bleeding, and scars were defined as wounds no longer bleeding but with the skin not yet healed. Missing parts of tails were defined as above in Study II.

4.4.2 Ear damage (II, III, IV)

In Study II, ear damage was assessed at the age of 4.5 months by examining each pig's ears visually. The scale and definitions used were developed during a pilot phase of this study, as follows: 0 = undamaged ears; 1 = scratches; 2 = evidence of recent bleeding; 3 = part of an ear missing. Scratches were defined as superficial narrow red marks on the skin that did not involve a cut through the epidermis. Missing parts of ears were defined by comparing the shape of the ear to that of an undamaged pig.

In Studies III and IV, ear damage was assessed at the age of four months (Study III) or six months (Study IV) by examining each pig's ears visually. The scale and definitions used were developed during a pilot phase of Study III, as follows: no damage = intact skin in both ears. Mild damage = scratches, wounds or scars in at least one ear. Severe damage = part of at least one ear missing. Scratches were defined as above in Study II. Wounds were defined as involving bleeding, and scars were defined as wounds no longer bleeding but with the skin not yet healed. Missing parts of ears were defined as above in Study II.

4.4.3 Oral-nasal behaviours (I, II, III)

Behavioural data were collected from videos by continuous observation. Video recordings were carried out with wireless Intellicam IPC04 video cameras, operated with Blue Iris software (Perceptive Software, USA). For the purposes of data collection, oral-nasal manipulation was defined as touching the target, i.e. an object or a pig, with the snout or mouth in a way that resulted in visible movement in the target.

In Study I, video recordings were carried out at the ages of one, two and eight weeks, i.e. twice during the pre-weaning period and again one month after weaning. Video recording was carried out on one day for each age, from approximately 10:00h to 14:00h. On each video, the first 8min of active time (defined as 50% or more of the piglets in the pen either sitting, standing, walking or running) and the first 4min of settling to sleep (defined as 80% or more of the piglets lying on the floor, with at least one of these moving) were selected for data collection. Data were collected on the frequency of the oral or nasal manipulation directed at the objects (recorded separately for paper, wood shavings, rope, the plastic ball or the plastic chewing stick) and oral or nasal manipulation directed at other piglets.

In Study II, video recording was carried out at the age of 4.5 months, i.e. after 2.5 months of exposure to the experimental objects or lack thereof, for one entire day. On each video, a 20min period before the afternoon feeding was selected for observation, defined as ending when the feeder started functioning. Due to variation in the time of feeding in the different rooms on the farm, the starting time of the observed periods varied between 14:20h and 15:20h. Data were collected on the frequency of the oral or nasal manipulation directed at the objects (recorded separately for wooden, plastic and metal objects) and oral or nasal manipulation of directed at other pigs (recorded either as belly-nosing or as targeting an ear, a face, a tail, a foot/leg, or any part of the rest of the body).

In Study III, video recording was carried out at the age of four months, i.e. after two months of exposure to the experimental objects or lack thereof, for one entire day. On each video, two periods were selected for observation: a 30min period before the morning provision of feed and straw, and a 90min period after nearly all the straw had been consumed. The first period lasted from 7:55h to 8:25h and the second, from 9:30h to 11:00h. Data were collected on the frequency of the oral or nasal manipulation directed at the objects (recorded separately for wooden and metal objects) and oral or nasal manipulation directed at other pigs (recorded separately for targeting a tail, an ear, a head excluding ears, a leg or any part of the rest of the body).

4.4.4 Human approach test (III, IV)

A human approach test was carried out at the age of six months, i.e. after four months of exposure to the experimental objects or lack thereof. The experimenter stepped into the pen at the midpoint of the pen wall facing the corridor and remained standing immobile. The moment chosen for this in each pen was when no pigs were already within 2m distance from that point in the pen. The experimenter was an unfamiliar person to the pigs, because all the practical arrangements had been carried out by farm workers; however there was the familiar element that the experiment was wearing overalls that the farm provided for all visitors, and therefore the odours in the overalls were typical to that farm. The recorded parameter was the number of seconds before three different individual pigs had touched the experimenter with the snout or mouth.

4.4.5 Piglet growth and mortality (I)

At weaning, each litter was weighed on a spring-dial hoist scale. To obtain the mean weight of piglets in that litter, the result was divided by the number of piglets. Additionally, data on pre-weaning mortality in each litter were obtained from the records of the farm staff.

4.4.6 Hospital pen transfers and mortality (II)

The difference in the number of pigs in each pen at the beginning of the study period, i.e. at two months of age, as compared to the end of the study period, at 4.5 months of age, was recorded for each pen. According to the farm staff, the reasons for removals of pigs from pens were in each case either death, culling or transfer to a hospital pen, but on-farm data were not available on how many of the missing pigs in each pen were attributable to each reason.

4.4.7 Breeder gilt approvals (III)

Data on the number of gilts that were approved as future breeder sows – a selection made by the farm owner when the gilts were six months old – was obtained from the farmer, recorded separately for each pen.

4.4.8 Pen hygiene (II, III, IV)

The presence vs. absence of soiling of the solid floor area in the pens was assessed on the same day as the tail and ear damage were scored. Data were collected using a dichotomous variable representing the presence vs. absence of wet faeces, either freshly defecated or older but soaked with urine, on the solid floor.

4.4.9 Costs of materials and labour (I, II)

Costs of each of the materials used (including chains, nuts and bolts used for suspending the objects) were calculated based on the lowest available prices in hardware stores in Finland. Labour costs were calculated by multiplying the average labour costs of a Finnish pig farm worker (including the salary and the obligatory employer contributions, such as pension and national insurance payments) by the number of working hours needed to provide the experimental materials and objects. The number of working hours included all the work needed: harvesting the wood, buying the other materials, constructing and storing the objects, attaching the objects before the arrival of the pigs in the pens and removing the objects after the pigs had left the pens. In Study I, the working hours recorded also included distribution of the daily provisions of paper. In Study I, the preparation, attaching and removals of objects were carried out by the experimenters, and in Study II, by the farm staff according to instructions from experimenters. In both studies, the recording of the time was carried out with the third batch of five, by which the experimenters or farm staff were assumed to have acquired sufficient routine to no longer become faster with further practice. Once the results on tail damage were known, the observed costs of materials and labour were compared to tentative estimates on the economic benefits of reductions in tail biting to the producer. A previous study on one commercial farm in Finland had shown that reducing tail biting lesions from 51% to 41% reduced the costs of treating wounds by 2.20 Euros per pig space per year (Niemi, J., pers. comm.). On this basis, a very tentative estimate was calculated for the average cost of reducing tail biting with the materials tested in these studies.

4.4.10 Methods to prevent observer bias

To avoid bias in data collection in Study I, the transfer of the weaned piglets to growing pens was carried out by the farmer, and the experimenters were kept blind to the treatments of origin of the piglets in the growing pens until all the scoring of tail damage and collection of behavioural data had been carried out. In pre-weaning behavioural data collection, as well as in behavioural data collection in Studies II and III, blinding was not possible because the experimental objects were visible on video; in these cases, the approach to minimise bias was a balancing across treatments of the order in which the videos were observed. The same approach was used in tail and ear damage assessments in Studies II, III and IV, in all of which the experimental objects were visible in the pens at the time of damage assessment. In the human approach test in Study IV, to exclude the potential effect of pigs in other pens in the same room becoming to some extent habituated to the presence of the experimenter in the room, the order of entering the pens was balanced across the treatments.

4.5 Statistical analyses

The statistical analyses were carried out at the pen level. Data that had been collected at the individual level, i.e. tail and ear damage data, were combined into pen-level averages prior to analysis, with the exception of tail damage data in Study I, which were analysed at individual level.

In Study I, the tail damage data were analysed with logistic regression, using the pre-weaning environment and batch number as predictive variables. For the analysis, the damage categories 1 and 2 were combined to form a category termed mild damage, and categories 3 and 4, a category termed severe damage; and the two batches that had experienced accidental feeder malfunction were combined to form Batch 1, and the three batches with no experience of feeder malfunction were combined to form Batch 2. The behavioural data at the ages of one and two weeks were analysed with a repeated-measures ANOVA; and the behavioural data at the age of eight weeks were analysed with an independent samples *t*-test, except for the question on object preference, which were analysed with a χ^2 Goodness of Fit test using the cumulative frequency in the two first recordings. The growth and mortality data were analysed with a Mann-Whitney *U* test. The statistical analyses were carried out with SPSS 18, except for the object preference data, which were analysed with Vassar Stats, and tail damage data, which were analysed with SYSTAT 12.

In Study II, the proportions of tail and ear damage categories 0 and 1, as well as the behavioural data, except for object preferences, were analysed with one-way ANOVA and pairwise comparisons with a Tukey's test. Proportions of the tail and ear damage categories 2 and 3 were analysed with a Kruskal-Wallis test. Proportions of preferences between different objects within the same pen were analysed with a related samples Friedman's test, followed with pairwise comparisons with a related-samples Wilcoxon Signed Rank test with Bonferroni corrections. Data on soiling of the floor were analysed with a χ^2 test. The statistical analyses were carried out with SPSS 21.

In Study III, the proportions of tail and ear damage were analysed with a Mann-Whitney *U* test. Behavioural data on manipulation targeted at pigs both before and after consumption of the straw, and on manipulation targeted at objects after consumption of the straw, were analysed with an independent samples *t*-test. Proportions of manipulation targeted at objects before consumption of the straw were analysed with a Mann-Whitney *U* test. Proportions of differences before vs. after straw consumption in the distribution of pig-directed manipulation across the different body parts of the target pig were analysed with a repeated measures *t*-test for targeting tails, ears, heads and legs in the experimental treatment and of ears in the control treatment; and with a related-samples Wilcoxon Signed Rank test for targeting the rest of the body in the experimental treatment and of tails, heads, legs and the rest of the body in the control treatment. Proportions of preferences between different objects within the same pen were analysed with a repeated measures *t*-test in the experimental treatment and with a related-samples Wilcoxon Signed Rank test in the control treatment. Data on soiling of the floor were analysed with a χ^2 test, and data on the percentages of pigs approved as breeders were analysed with a Mann-Whitney *U* test. The statistical analyses were carried out with SPSS 23.

In Study IV, the mean scores for tail and ear damage were analysed with one-way ANOVA and pairwise comparisons with a Tukey's test. A $\log_{10}$ transformation was carried out for the data on tail damage and latency to approach an unfamiliar human. Proportions of soiling of the floor were analysed with a χ^2 test. The statistical analyses were carried out with SPSS 21.

5. Results

The main results are shown in Table 2. More details results are given below in sections 5.1 – 5.10.

Table 2. *Overview of the main results on tail and ear damage. The percentages refer to the mean pen-level average prevalence for each damage category.*

Study number	Treatments	Tail biting damage, %			Ear biting damage, %		
		No damage	Mild damage	Part of tail missing	No damage	Mild damage	Part of ear missing
I	Control: ball pre-weaning; plastic stick and ropes shavings post-weaning; wood shavings in both	23	69	8	No data collected		
	Experimental: all of the above, plus paper and ropes before weaning	31	68	1			
II	Control: straw rack	33	37	30	20	80	0
	Wood: straw rack and fresh wood 30cm/pig	56	16	28	37	63	0
	Plastic: straw rack and plastic pipe cross	42	39	19	23	77	0
	Branching chains: straw rack and complex chains	44	40	16	18	82	0
	WPB: All of the above	56	21	23	40	60	0
III	Control: straw 20g/pig/day, plus dry wood and metal chain	83	10	7	34	66	0
	Experimental: straw 20g/pig/day, plus fresh wood 20cm/pig	87	7	6	32	68	0
IV	Control: straw rack	55	34	11	7	92	1
	Wood: straw rack and fresh wood 10cm/pig	65	24	11	27	62	1
	Plastic: straw rack and plastic pipe 10cm/pig	41	34	25	10	89	1

On Studies I–III, further details are available in the respective publications. On the unpublished dataset of Study IV, descriptive data are presented in Table 3.

Table 3. *Descriptive data from Study IV. The tail damage categories were as follows: 0 = No damage; an intact and entire tail. 1 = Mild damage; scratches, wounds or scars. 2 = Severe damage; part of tail missing. The ear damage categories were as follows: 0 = undamaged ears; 1 = superficial scratches; 2 = evidence of recent bleeding; 3 = part of an ear missing.*

Parameter	Wood treatment		Plastic treatment		Control treatment	
	Mean	SD	Mean	SD	Mean	SD
Tail damage score	0.9	1.0	1.6	1.1	1.1	1.0
Ear damage score	1.3	0.5	1.8	0.6	1.9	0.4
Latency of the three first pigs to touch an unfamiliar human in the home pen, seconds	8.8	5.4	17.3	10.2	15.4	9.5
Percentage of pens with faeces on the solid part of the floor	31%		8%		6%	

5.1 Tail damage (I, II, III, IV)

In Study I, pre-weaning access to paper and rope did reduce the severity of post-weaning tail biting, while not affecting the percentage of tails that remained entirely undamaged. There was no observable tail damage prior to weaning, so all the tail damage observed at the age of eight weeks can be assumed to have occurred after weaning, i.e. while the two treatment groups were kept in identical environments. An unintended feature of the study was that due to accidental feeder malfunction in the post-weaning period, two of the five batches of weaner piglets experienced one to two days of hunger. This parameter was included in the analysis. It was found that in piglets that did have tail damage, its severity was increased by both expected factors: by having been in the control group pens before weaning and by having experienced hunger after weaning due to feeder malfunction. Severe damage (evidence of chewing or puncture wounds with swelling and signs of infection, or partial or total loss of the tail) was more prevalent in the control group ($P<0.01$) and in the batches with feeder malfunction ($P<0.001$). Mild damage (healed or mild lesions, or evidence of chewing or puncture wounds without swelling or infection) was less prevalent in the control group (*P*<0.05) and in the batches with feeder malfunction (*P*<0.05). There was no significant difference in the prevalence of undamaged tails between the treatment groups. There also was no significant difference in the prevalence of undamaged tails between the batches with vs. without accidental feeder malfunction.

In Study II, the prevalence of undamaged tails was significantly higher in the treatments with either wooden objects only or wooden, plastic and metal objects, than in the control treatment (*P*<0.05). The prevalence of the mildest tail damage category, defined as missing tail-end hairs and/or blood on the tail, was significantly lower in the treatments with either wooden objects only, or with wooden, plastic and metal objects, than in the treatment with plastic objects, the treatment with branching metal chains or the control treatment (*P*<0.01). There were no significant differences between treatments in the categories of more severe tail damage.

In Studies III and IV, there were no significant differences in tail biting damage between the treatment groups. In Study IV, there was a tendency for milder tail damage in the treatment with wooden objects (mean tail damage score 0.9) as compared to the treatment with plastic objects (mean score 1.6, *P*=0.09) but no difference as compared to the control treatment (mean score 1.1, *P*>0.1) when the damage scale was from 0 (no damage) to 2 (severe damage).

5.2 Ear damage (II, III, IV)

In Study II, the prevalence of undamaged ears was significantly higher in the treatments with either wooden objects only or wooden, plastic and metal objects, than in the treatment with branching metal chains (*P*<0.01 in the overall ANOVA result). There were no significant differences between treatments in any of the other categories of ear damage.

In Study III, there was no significant difference in ear biting damage between the treatment groups.

In Study IV, the prevalence of ear damage, expressed as the mean ear damage score per pen, was lower in the treatment with wooden objects (mean score 1.3) than in the treatment with plastic objects (mean score 1.8) or the control treatment (mean score 1.9, *P*<0.01), when the damage scale was from 0 (no damage) to 3 (severe damage).

5.3 Oral-nasal manipulation of objects (I, II, III)

In Study I, the frequency of interacting with objects in the pre-weaning environment was higher in the experimental group with sisal ropes, a plastic ball, paper and wood shavings, as compared to the control group with a plastic ball and wood shavings. The difference was significant during both ages, one and two weeks, and in both behavioural contexts, i.e. while active and while settling to sleep (*P*<0.001 in each case). Within-pen comparisons in the experimental group showed that across both ages, paper and rope elicited more use than the plastic ball (*P*<0.01). Frequency of interacting with the plastic ball did not differ between the treatment groups. Frequency of interacting with wood shavings could not be quantified as wood shavings were visible in none of the videos, suggesting they had fallen through the slatted floor soon after they had been provided and before video recording started. At the age of eight weeks, in the growing pens that were identical for both treatments, there were no significant differences in object-directed manipulation, but there was a tendency for the control group to manipulate objects more frequently than the experimental group (*P*<0.1).

In Study II, the frequency of interacting with objects was higher in the treatments that either had wooden objects only, or that had wooden, plastic and metal objects, as compared to either the treatment with branching metal chains or to the control treatment (*P*<0.001 in the overall ANOVA result). Within-pen comparisons in the treatment with wooden, plastic and metal objects showed that the frequency of manipulating wooden objects was higher than the frequency of manipulating branching chains (*P*<0.05), and that for any of the other pairings of object types, the differences in manipulation frequency were not significant.

In Study III, the frequency of interacting with objects was higher in the experimental group with objects of recently harvested wood than in the control group with objects of commercially sourced wood and metal feeder chain. The difference was significant both before and after consuming the straw provision (*P*<0.01 and *P*<0.05, respectively). Within-pen comparisons of pre-consumption object preferences showed that in the experimental treatment, the frequency of manipulating the long piece of wood was higher than the combined frequency of manipulating the two short pieces (*P*<0.05); and that in the control treatment, the frequency of manipulating the piece of commercially sourced wood was higher than the frequency of manipulating the metal feeder chain (*P*<0.05). There were no significant post-consumption object preferences within either treatment group.

5.4 Oral-nasal manipulation of pen-mates (I, II, III)

In Study I, the frequency of directing oral-nasal manipulation at other piglets in the pre-weaning environment was lower in the experimental group with sisal ropes, a plastic ball, paper and wood shavings, as compared to the control group with a plastic ball and wood shavings. The difference was significant during both ages, one and two weeks, and in both behavioural contexts, i.e. while active and while settling to sleep (*P*<0.001 in each case). At the age of eight weeks, in the growing pens that were identical for both treatments, there were no significant differences in the frequency of directing oral-nasal manipulation at other piglets.

In Study II, there was no significant difference between the treatment groups in the frequency of directing oral-nasal manipulation at other pigs.

In Study III, the frequency of directing oral-nasal manipulation at other pigs before consuming the straw provision did not differ between the treatment groups. After consuming the provision of straw, the frequency of directing oral-nasal manipulation at other pigs was lower in the experimental treatment than in the control treatment (P<0.05).

5.5 Response to an unfamiliar human (III, IV)

In Study III, there was no significant difference between treatments in the latency to approach an unfamiliar human.

In Study IV, the latency for the first three pigs to have touched an unfamiliar human was shorter in the treatment with wooden objects (mean latency 8.8s) than in the treatment with plastic objects (mean latency 17.3s) or the control treatment (mean latency 1.5s, F=5.2, P<0.05).

5.6 Piglet growth and mortality (I)

There was no significant difference between the treatment groups in the weaning weight or in pre-weaning mortality.

5.7 Hospital pen transfers and mortality (II)

There was no significant difference between the treatment groups in the number of pigs that were removed from the pens during the duration of the study because of death, culling or transfer to a hospital pen.

5.8 Breeder gilt approvals (III)

There was no significant difference between the treatment groups in the number of gilts that were approved to become future breeders.

5.9 Pen hygiene (II, III, IV)

There was no significant difference between the treatment groups in the occurrence of wet faeces on the solid part of the floor.

5.10 Costs of materials and labour (I, II)

In Study I, the total material and labour costs for furnishing 217 piglets in 30 pens with the quantities of rope and paper used in the study were 133 Euros. As the prevalence of severe post-weaning tail biting (defined as wounds with inflammation or part of tail missing) weeks was 32.1% in the control group, representing ordinary practices on this farm, and 9.8% in the experimental group with added materials for manipulation pre-weaning, it was calculated that being in the experimental group spared the tails of 49 pigs from severe damage. If these tails were to remain without severe damage until slaughter, this saving of 49 tails was estimated to improve productivity by 119 Euros. In this case, the net cost of furnishing farrowing pens with paper and ropes, in the way they were used in this study, would be 0.11 Euros per piglet, if calculated across all the piglets in the experimental group, or 0.29 Euros per spared tail.

In Study II, the total material and labour costs for furnishing 152 pigs in 14 pens with the quantities of recently harvested wood used in the study were 270 Euros. As the prevalence of mild tail biting (defined as wound on the tail but no part of the tail missing) was 36.2% in the control group and 16.4% in the experimental group with wooden objects, it was calculated that being in that experimental group spared the tails of 36 pigs from mild damage. If these tails were to remain without any damage until slaughter, this saving of 36 tails was estimated to improve productivity by 230 Euros. In this case, the net cost of furnishing finishing pens with objects made of recently harvested wood, in the way they were used in this study, would be 0.26 Euros per pig, if calculated across all the pigs in the experimental group, or 1.11 Euros per spared tail.

6. Discussion

6.1 Tail and ear damage

In Study I, the main finding was that it was possible to reduce post-weaning tail biting by providing additional materials for manipulation to the pre-weaning environment. This hypothesis had already been supported by the earlier findings of Moinard et al. (2003), who found that farms using straw before weaning supported less tail biting at later ages as compared to farms not using straw before weaning. However, in that study it was not possible to differentiate between the beneficial effects of pre-weaning and post-weaning straw because most of the farms using straw pre-weaning also used it post-weaning. Even though there is evidence that providing growing-finishing pigs with a small amount of substrates has a more pronounced beneficial effect if the pigs also have had experience of substrates in their early life (Day et al., 2002), the prevalence of harmful behaviours is influenced more by the availability of materials for manipulation in the current environment, as compared to the availability of materials in past environments (van de Weerd et al., 2005). Hence the need for the current study, in which the experimental and control groups were kept in identical post-weaning environments.

It is worth noting that the ordinary set of pre-weaning materials provided on that farm, functioning as the control treatment, did not represent an entirely barren environment either: it was compliant with EU legislation (European Union, 2008) and included provision of wood shavings twice a day and continuous access to a suspended commercial plastic ball, the marketing claims for which implied a capacity to reduce biting of other pigs. The causal mechanism behind the reduced post-weaning tail biting was not investigated in the study, but as no significant difference between treatments was found in the post-weaning frequency of manipulating objects or pen-mates, the causes are likely to go deeper than simply forming a habit for which types of targets to chew on. The finding was similar to that of van de Weerd et al. (2006), who found a lower prevalence of tail biting in treatment groups with straw on the floor or in a rack, as compared to a treatment group with commercial Bite-Rite plastic chewing sticks, while these treatment groups did not differ in the frequency of oral-nasal manipulation directed at other pigs. The mechanisms of the observed benefits in the current study therefore require further study. One of the potential mechanisms to test could be as follows: if oral-nasal manipulation is a behavioural need in piglets in early life already (which is quite possible, judging from the propensity of neonatal piglets to burrow in nest material), then lack of suitable materials may cause stress, which in turn may disrupt normal development of the stress-regulation mechanisms (reviewed in Telkänranta and Edwards, 2018). Another question for further study is the quantity of material needed in the post-weaning environment to maintain the behavioural benefits gained in the pre-weaning environment, as moving pigs to an environment with markedly less materials for manipulation than before can increase tail biting (Munsterhjelm et al., 2009).

In Study II, the main finding was that the treatment with objects made of recently harvested wood did reduce tail and ear biting as compared to the control treatment, while the treatments with plastic and metal objects did not. These findings are in line with the conclusion reached by Bracke et al. (2006) that metal objects are not sufficient for pigs and that wood does bring some welfare benefits, although less than straw. However, the results of the current study regarding comparison among materials may be confounded by the different quantities and locations of the objects made of different materials. Because wood was the only one of these materials that in the pilot phase could be placed above the solid floor area without increasing the pigs' defecating on that area, and conversely also the only one of these materials that could not be placed above the slatted floor area without causing the pigs to switch some of their defecating behaviours to the solid floor area, the wooden objects were placed above the solid floor, where there also was more space for the objects; and the plastic and metal objects were placed above the slatted floor. It is therefore possible that the difference in efficacy to reduce tail and ear biting was partly due to the larger quantity of wooden objects, and/or that there is something inherent in manipulating objects on a solid floor that the pigs perceive differently from doing it on a slatted floor. One such speculative possibility might be the innate propensity of pigs to build resting nests of vegetation, including branches (Stolba and Wood-Gush, 1989), which might induce pigs to associate the odour of recently harvested wood with a place for sleeping and therefore not for defecating, but this possibility requires further study. Furthermore, the quantity of wooden objects in the current study – which was seven logs per pen, with an average of 11 pigs per pen, constituting 30cm of wooden log per pig, may have been one reason why the current study found a reduction in tail biting while some previous studies on wooden objects have not. Nannoni et al. (2016) compared metal chains, wooden logs, wooden briquettes and edible blocks to each other by providing only one object per pen – which, with five pigs per pen, constituted 5cm of wooden log per pig – and did not find any significant differences in behaviour, hair cortisol or tail and skin lesions. Similarly, Cornale et al. (2015) used wooden logs at 4cm per pig and did not find an effect on cortisol secretion, although they did find a significant reduction in tail damage.

In Study I, the reduction in tail biting was only reflected in severity, i.e. whether those piglets that had tail damage only had superficial scratches as compared to inflammation or partially amputated tails, but not in the total number of tails affected by biting. Conversely, in Study II, the reduction in tail biting was only seen in the total number of tails affected, i.e. the experimental groups with recently harvested wood had a higher prevalence of entirely undamaged tails than the other treatment groups, but in the tails that had been bitten there was no difference between treatment groups in the severity of the damage. This suggests that the experimental treatments in Study I vs. II were able to reduce different types of tail biting. Taylor et al. (2010) describe three distinct types of tail biting that differ in their motivational factors, behavioural characteristics and damage type. Two-stage tail biting, which is characterised by initially engendering only mild, superficial damage and caused mainly by lack of suitable materials to chew, may have been the type that the wooden objects in Study II were able to reduce. The two other types of tail biting, sudden-forceful and obsessive, are more likely than two-stage biting to cause partial amputation of the tail. Their causes are not yet fully understood, though sudden-forceful biting is often seen during competition over resources. The results of Study I may have been a consequence of a period of hunger triggering tail-biting behaviour that to some extent spread in the group, which has been termed epidemic tail biting by Valros (2018). A potential question for further research would be whether early development of stress regulation mechanisms also plays a part in the development of either or both these types of tail biting. Such a possibility is supported by the findings that piglets reared in different early environments show differences in cortisol secretion in later life. In a study on piglets reared either indoors or outdoors and transferred to identical environments at weaning, de Jonge et al. (1996) found that in adulthood the group from the indoor early environment had a higher basal cortisol level and a more pronounced cortisol response to a restraint stressor. In another study comparing piglets reared in either a standard commercial indoor environment or in pens with added space, substrates and a non-crated mother, transferred to identical environments at weaning, Chaloupková et al. (2007) found that at the age of six months the group from the standard rearing environment showed a higher cortisol response and a decrease in meat pH after slaughter. Similarly, studying piglets reared in either barren farrowing pens or in farrowing pens with a thin layer of wood shavings and chopped straw on the floor, transferred to identical environments at weaning, Munsterhjelm et al. (2010) found that at five months of age, those from the standard rearing environment showed more tail biting and a blunted circadian rhythm of cortisol secretion.

In Study III, there was no difference between treatment groups in tail and ear damage. This may have been partially caused by the low overall prevalence of tail biting on that farm (86% of the pigs in that study had an entirely intact tail with not a single scratch). The farm also had more space per pig than the farms in the other studies where the pigs were of similar age. The mean floor area per pig on this farm was $1.7m^2$, whereas in Studies II and IV, the mean floor areas per pig were $0.7m^2$ and $1.0m^2$, respectively. Some, but not all, previous studies have found a positive correlation between stocking density and risk of tail biting (rev. in D'Eath et al., 2014). Furthermore, this was the study in which the difference between treatments was smallest. Both groups received daily provisions of straw, and the objects continuously available in the pens had been selected to represent a higher quantity of a putatively more attractive material in the experimental treatment vs. two different materials in the control treatment. This type of difference between treatments may be too small to yield measurable reduction in tail or ear damage. A similar outcome was reported by Statham et al. (2011), who found no difference in tail biting between treatments involving either straw or wood shavings, which may have had relatively similar effects.

In Study IV, in which the treatments with wooden vs. plastic objects involved the same quantity of material, the treatment with wooden objects was again the only one to reduce tail and ear damage, although for tails this was only a tendency. It is interesting to note that this tendency was in comparison to plastic objects, not to the control treatment. While one cannot draw conclusions from tendencies only, at least this suggests that the plastic objects were not substantially more effective than having no objects at all. There has been very little research on the efficacy of plastic objects in reducing tail biting, but in expert opinions collected by Bracke et al. (2006), they were not mentioned among the recommended materials.

The lack of efficacy of the wooden objects in reducing tail biting in Study IV may also have been partially caused by this being the study with the smallest quantity of wood per pig: approximately 10cm per pig, while the quantity in Study II was 30cm per pig and in Study III, 20cm per pig. However, in a study by Cornale et al. (2015), providing wooden logs at a quantity corresponding to only 4cm per pig was sufficient to cause a significantly lower level of tail damage as compared to a control group. In contrast, another study also using 5cm of wood per pig, by Nannoni et al. (2016), did not find a reduction in tail biting. However, it is worth noting that comparisons between Studies I–IV, as well as comparisons to other studies, have to be made with caution. Each of them was an independent study on a different farm and with varying object designs. The studies also had been designed to have either a higher or lower level of difference between the treatments within each farm. For instance, the difference between treatments in Study IV was designed to be small, in order to see whether such a nearly cost-free difference would elicit any effects at all. The difference between pre-weaning treatments in Study I was designed to be substantial, in order to see whether it was at all possible to reduce post-weaning tail biting with pre-weaning material on a partially slatted floor.

Another reason for caution in comparisons among these four studies was the different scoring systems used for tail damage. While the system of Kritas and Morrison (2004) worked well with the 8-week-old piglets, the pilot phase with finishing pigs showed that for the more intense damage seen at that later age, a different scoring system was needed to yield more nuance on the severely damaged tails, which was developed for Study II. As the experience from that study indicated there still was an unnecessary extent of nuance in the mild damage category, the scoring system was further revised to be used in Studies II and IV. Comparison to other studies also needs to be done with caution as scoring systems and definitions for words such as ‘mild’ and ‘severe’ differ across studies (rev. in Buijs and Muns, 2019).

It is also important to note that tail and ear biting still occurred in all the treatment groups. While some of the treatments were successful in reducing its prevalence or severity, none of the treatments came even close to solving the problem. The same has been true in other studies providing pigs with supplementary objects on industrial farms or similar experimental conditions (rev. in Buijs et al., 2019), and further improvements in the materials and object designs are needed. Furthermore, as tail biting is known to be a multifactorial problem, affected by stress, illness, ambient temperature, deficiencies in the quantity and quality of food and several other factors (rev. in D’Eath et al., 2014; Godyn et al., 2019), solving the problem also continues to require further improvements in all these fields.

6.2 Behavioural observations

In Study I, providing more materials in the pre-weaning environment did increase object-directed manipulation and decrease piglet-directed manipulation as compared to the control group. The finding was in line with that of Hötzel et al. (2004), showing that piglets in an outdoor environment directed less oral-nasal manipulation at each other than piglets in an indoor environment that was environmentally substantially less complex than the outdoor environment. This difference no longer persisted in the post-weaning environment in which both treatment groups had identical materials. This result is in line with the earlier finding that pig behaviour is more strongly affected by the current than earlier environments (van de Weerd et al., 2005). However, it is worth noting that the severity of tail damage did differ significantly among the treatment groups even while their behaviour at the same age did not. The video recordings for behavioural observation were carried out on the day before scoring the tail damage, and no observable difference in the environment took place between those days. One potential explanation for this discrepancy between behaviour and tail damage could be that there actually may have been a difference in behaviour as well, but the duration of time for which behaviour was observed on video, 12min per pen, may have been too short to detect significant differences. Another potential explanation is that the frequencies of oral-nasal manipulation targeted at objects and pen-mates may be insufficient predictors of tail biting risk. This possibility is supported by the study of van de Weerd et al. (2006), which showed a difference between treatment groups in tail damage while there was no difference in the frequency of oral-nasal manipulation of other pigs. A third possibility is that specific characteristics of oral-nasal behaviours, such as the type of behaviour (e.g., gentle social touch vs. biting) and the intensity of behaviour, were not differentiated in this study and could carry more welfare-relevant information. The same lack of detail in distinguishing between different types of oral-nasal contact also warrants caution in comparing results of different studies to each other (rev. in Buijs and Muns, 2019).

As a separate note on the ability of objects to sustain piglets' attention, the commercial plastic ball for pigs, marketed under the name "Anti-Bite", did not quite live up to its name: it elicited almost no use at all, either in the experimental treatment or in the control treatment, despite being the only continuously available object provided for manipulation in the latter. Instead of using the ball as an outlet for their need for biting and rooting behaviours, the piglets targeted each other, as found in Study I, and various body parts of the crated sow, as found in a separate study based on the same videos that included an analysis of manipulation redirected at the sow (Swan et al., 2017).

Taken together, the findings of the current study further highlight the need for increased consideration of and research on behavioural needs of young piglets, which has been called for by Baxter et al. (2011), among others.

In Study II, pigs in the treatments with objects of recently harvested wood showed more object-directed manipulation than pigs in the treatments with a branching chain or in the control treatment. The frequency of manipulation in the treatment with plastic objects was between the above, with no significant difference to either. The results suggest that adding complexity to a metal chain by constructing a branching design, which was expected to increase pigs' interest in it by enabling a larger repertoire of manipulating movements (Bracke and Koene, 2019), may not be enough to substantially improve the ability of a metal chain to sustain pigs' interest. One of the factors affecting this and requiring further study is whether pigs' defecation patterns in intensive farming preclude positioning of chains on the solid floor area, on which the end of the longest branch of the chain could lie horizontally. Domestic pigs observed in a semi-natural environment always defecate away from the resting nest that is made of branches and other types of plant material (Stolba and Wood-Gush, 1989). Therefore, it may be possible that plant-based materials in a pigpen can cause pigs to defecate elsewhere, while non-plant materials such as a metal chain may not have that effect.

Furthermore, it is interesting to note that while the frequency of engaging with objects did not differ significantly between the wood and plastic treatments, the prevalence of tail damage did. This finding could suggest that the frequency of engagement with an object may be an insufficient proxy measure for the object's ability to reduce tail biting or meet a pig's needs. This possibility is supported by Beattie et al. (2001), who found that pigs provided with an overhead rack showed more object interaction but also more tail biting than a control group, and by Zwicker et al. (2013), who found that two treatments that differed significantly with respect to the frequency of object interaction – a pellet dispenser vs. a trough with bark compost – did not differ regarding the frequency of manipulation targeted at other pigs. On manipulation targeted at other pigs, the findings of Study II were similar to those in Study I and that of van de Weerd et al. (2006): despite a significant difference in tail damage between treatment groups, no significant difference in the frequency of pig-directed manipulation was found. The potential causes may be the same as those discussed regarding Study I. However, there may have been a further confounding factor in Study II. It is possible that pigs with wooden objects redirected less oral-nasal manipulation at each other than pigs in the other treatments, but at the same time engaged in more competition over the objects, which would also have been recorded as oral-nasal behaviours in the data.

In Study III, the objects made of recently harvested wood again elicited more object manipulation than the objects in the control pens, one of which was a piece of commercially sourced wood. Within-pen comparisons in object use in the control pens suggested that in line with the expert opinions discussed by Bracke et al. (2006), metal chain is not a very attractive material, even in the more complex structure that was provided by using feeder chain instead of ordinary metal chain: it elicited less object interaction than the piece of dry, commercially sourced wood. In the experimental pens, within-pen comparison of object use showed that the long wooden log over the solid floor area, where the provision of straw was also distributed, elicited more interaction use before but not after the provision of straw, as compared to interaction with the two short wooden logs at the pen corners over the slatted floor area. Once the provision of straw had been distributed and consumed, the difference between object interactions with the long vs. short logs was no longer significant. This finding suggests the pigs may have used the wooden log as an outlet for oral-nasal behaviours in anticipation of straw, which is suggested by an earlier finding that pigs on restricted feeding show a higher frequency of substrate manipulation than pigs fed *ad libitum* (Zwicker et al., 2013).

Interestingly, when comparing pig-directed oral-nasal manipulation between treatments before and after the provision of straw, its post-straw frequency was lower in the experimental treatment than in the control treatment, where it remained as high as it had been pre-straw. The mechanism of this was not investigated in the study and is not clear, but the results suggest that some characteristic in the quality and/or quantity of wood in the experimental pens had additive effects with the small provision of straw. Additive effects of a different combination of materials, namely wood and rope, were previously reported by Trickett et al. (2009). In the current study, despite lack of treatment effects on tail and ear damage, these behavioural results suggested pig welfare may have been marginally better in the experimental treatment than in the control treatment. However, it is important to note that oral-nasal manipulation of pen-mates continued in the experimental pens as well, though reduced, which suggests there still was a substantial extent of unmet and therefore redirected need for oral-nasal behaviours.

Any interpretations of the results on pig-directed activity are to be made with caution because the data collection system did not differentiate between different types of oral-nasal behaviour, such as play, fighting or redirected rooting. Furthermore, the data did not include information on the intensity of the behaviour, which does not always correlate with the frequency and may carry more information on the significance of the behaviour to the pig (Bracke, 2007). Nor did the data include information on different types of inactivity, which also can differ in their implications for animal welfare: for instance, resting contentment is a different state than depression-type inactivity (rev. in Fureix and Meagher, 2015). When interpreting results on object-directed manipulation, it is also useful to bear in mind that it does not always indicate an improvement in behaviour but can be motivated by frustration, for example. Furthermore, some studies have found an increase in object manipulation before a tail-biting outbreak (Larsen et al., 2016).

The human approach test is assumed to provide information on the level of fearfulness (rev. in Reimert et al., 2014) and may therefore be useful as a proxy measure for long-term stress. In the current study, the rationale for measuring the latency of a third pig to touch the experimenter, instead of the first pig, was to reduce the effect of random differences in personality types. Like other vertebrates, pigs show substantial individual differences in personality traits that influence their responses to novel situations (Bolhuis et al., 2004; Luo et al., 2019). The likelihood of any one pen containing three pigs with a highly novelty-seeking personality, or with very low fearfulness, is probably lower than the likelihood of a pen containing one such individual. Of the current studies, in Study III there was no significant difference between the treatment groups in their latency to approach an unfamiliar human. Together with the finding that there also was no significant difference in tail and ear damage, this suggests that the difference between the experimental and control treatments, as perceived by the pigs, was smaller than in the other studies. It is possible that the daily provision of straw, while very small in quantity, has nevertheless been salient enough to override most of the effects of having either of the two different combinations of objects. By contrast, in Study IV, in which straw was in a rack instead of providing it daily, the magnitude of the difference between treatments in the human approach test was quite substantial. The mean latency for the third pig to touch the observer was 9s in the pens with wooden objects, 17s in the pens with the plastic objects and 15s in the pens with no added objects. A previous study on pigs with access to straw vs. barren-housed pigs also found the former to be associated with a shorter latency in a human approach test (Reimert et al., 2014). If a human approach test is assumed to be a useful proxy measure for stress, then this suggests there may have been something in the characteristics of recently harvested wood that had a beneficial effect, especially in the absence of daily provisions of straw. The quantity of wooden log and plastic pipe in Study IV was the same – approximately 10cm per pig in each treatment – indicating the difference lies in quality. Further research is needed to investigate whether access to recently harvested wood has stress-reducing effects and if so, via which mechanisms.

6.3 Efficacy of plant-based vs. synthetic materials

The design of the Studies II, III and IV included asking whether tail biting would be reduced by providing plastic or metal objects with slight additional complexity, i.e. more than a simple piece of pipe or chain, based on the assumption that the complexity would enable the pigs to interact with the object in multiple ways. Each of the designs used in the study had already been in use on some other commercial farms, and at least some of those farmers in question considered them worth using. Nevertheless, and contrary to expectations, none of the metal and plastic objects that were tested against a control treatment (that had no added objects) showed significant differences in the effect on tail or ear biting as compared to the controls.

The materials that did reduce tail and/or ear damage scores were all plant-based: paper, natural fibre rope and recently harvested wood. One of the key characteristics of Studies II, III and IV was the emphasis of using wood from trees that had been felled within the past two months before the pigs first had access to it. The wood had not undergone any drying processes, as compared to commercially sourced wood that has usually been dried in a kiln and stored for years to ensure dryness before selling (Möttönen, 2006). The commercial drying process substantially changes several characteristics of the wood, such as its moisture content and its chemical composition (Brand et al., 2011), affecting odour and taste. The odour of recently harvested wood is intensive enough to be easily discerned by a human nose; similarly, its taste is distinctly different from that of dried wood. Odour is known to be one of the key characteristics in determining an object's ability to sustain the interest of pigs (van de Weerd et al., 2003), and olfaction is the most important sense for most mammals (Nielsen et al., 2015). Another difference between recently harvested and commercially sourced wood is that the former appears to have a softer, slightly yielding consistency when biting, which was verified during the pilot phase by the lead author biting into pieces of recently harvested wood herself. During the pilot and the studies, the pieces of wood gradually lost material from the surface, suggesting that the pigs were ingesting small edible particles. The use of recently harvested instead of commercially dried wood also provides a safety benefit: according to personal experience, recently harvested wood does not break into splinters when chewed, which dried timber sometimes does. In Finland, this potential risk of splinters has previously resulted in some of the personnel at Evira, the Finnish Food Safety Authority, unofficially cautioning against giving wooden objects to pigs (Mikkonen, pers. comm.). All of this may mean that recently harvested wood, resembling living plant matter, is a more species-relevant and salient material to pigs than commercially dried timber because wild boars consume a variety of plant-based food sources (Graves, 1984), as do domestic pigs when kept in a semi-natural environment (Solba and Wood-Gush, 1989). The use of wood in objects for pigs has been investigated in some studies, including the following: in an epidemiological study, tail biting was found to be less prevalent on farms providing wooden objects than on farms providing metal chains (Smulders et al., 2008). In an experimental study, growing-finishing pigs were provided with logs of the hardwood species black locust *(Robinia pseudoacacia)* in pieces with a length of 35cm and diameter of 6 to 10cm, allocating two such pieces per pen, each pen housing an average of 16 pigs. The results showed a lower level of tail biting damage as compared to a control group but no difference in cortisol measures (Cornale et al., 2015). In another experimental study, weaned piglets were provided with logs of poplar, without specifying which poplar species, in pieces with a length of 35cm and diameter of 10cm, allocating one such piece in a pen of five piglets, and finding no beneficial effects (Nannoni et al., 2016). While there may have been many factors influencing the contrasting results of the two above studies, one of the possible explanations is the thickness of the logs relative to the age of the pigs, specifically mouth size. During the pilot phase preceding Studies II–IV, it was found that weaned piglets at one to two months of age are only able to place their jaws around a piece of wood if it has a diameter of approximately 4cm or less. Logs with a diameter of 10cm, as in the study of Nannoni et al. (2016), can only be gnawed at with the front teeth, which may be a different and less satisfying experience for pigs as compared to chewing with molars (rev. in Buijs and Muns, 2019).

Details of the type of wood are not always reported, even in experimental studies. In some cases, the objects are referred to as pieces of wood (Tönepöhl et al., 2012), wooden logs (Douglas et al., 2012; Fàbrega et al., 2019), wooden beams (Larsen et al., 2019) or wooden blocks (Trickett et al., 2009), indicating that at least in some cases the material is likely to be commercially sourced wood. Objects described as logs or branches are likely to not have been of commercially processed timber, but the time spent in storage before the commencement of the studies is not usually reported despite its substantial effect on odour, taste and hardness. It is therefore difficult to assess what effect those factors may have had on a finding such as logs being inferior to straw racks in attracting pigs (Fabréga et al., 2019) or the availability of a wooden log not affecting cortisol (Cornale et al., 2015). Recently however, there has been an increase in more detailed studies on wood. A comparison between four species of wood – the European beech *(Fagus sylvatica),* European larch *(Larix decidua),* Sitka spruce *(Picea sitchensis),* and Scots pine *(Pinus sylvestris)* – showed a preference for spruce but no difference in tail biting attributable to tree species (Chou et al., 2018).

Especially for the paper and rope, the characteristics also included destructibility and deformability, which are efficient in sustaining pigs' interest (Bracke, 2007; van de Weerd et al., 2009). Paper is destructible, and natural fibre rope is deformable even for suckling piglets. During Study I, it was observed that while the bite force of piglets is not yet strong enough to chew the ropes to pieces, the piglets' oral-nasal manipulation does have the effect of separating the fibres. By the time of weaning, the fibres of the ropes in the farrowing pens had become separated and each rope was tassel-like but nearly all the fibres of the rope were still intact. However, as the main research question of Study I was whether it was possible to reduce post-weaning tail biting by adding pre-weaning materials, the experimental design did not include investigating how much each of these materials, paper and rope, contributed to the beneficial effect, or whether one of the materials would have had the same effect even if used alone. This question, too, is open for future study. A working hypothesis would be that paper could be more effective than rope because other studies have shown that piglets provided with paper and rope simultaneously spend more time interacting with paper than with rope (Lewis et al., 2006); that substrates on the floor are more attractive for suckling piglets than hanging objects (Yang et al., 2018); and that novelty of objects or substrates is highly efficient in eliciting interaction (Trickett et al., 2009). In Study I, it was anecdotally seen in the video recordings used for data collection (results not reported) that the daily arrival of paper invariably caused a long, intensive bout of oral-nasal activity with the paper as well as intensive bouts of social, locomotor and object play. Another open question is safety. Newspaper cannot be recommended as a material for pigs before there is further information on whether it has any effects on pig health. In the study, the safety precautions included limiting the quantity of paper given at a time, only using non-glossy paper with no staples, and storing the newspapers for a minimum of two months before giving them to the piglets. Storage time reduces the amount of toluene and other volatile compounds that are present in fresh newspaper ink (Caselli et al., 2009), but it is nevertheless possible that the chemicals present in the paper itself may have adverse health effects (Binderup et al., 2002).

The two non-plant materials used in the current studies, plastic and metal, have received relatively little attention. Scott et al. (2007) provided growing-finishing pigs with suspended cross-shaped objects made of plastic (polythene) pipes, similar to those used in the current study. One of the treatments involved four such objects per pen and another treatment, one object per pen, when in both cases there were 32 pigs per pen. Their results showed that with both object quantities, the proportion of time spent interacting with the plastic objects was very low, below 2%, and with no significant difference between one vs. four objects per pen. Metal objects have been considered unsuitable for pigs, according to a survey of expert opinions (Bracke et al., 2006). Another survey of expert opinions by Bracke and Koene (2019) assessed the branching-chain design as substantially better than ordinary single chains. By contrast, in the current Study II, in which one of the treatments consisted of such branching chains, no welfare benefits were found over the control treatment with a single chain.

It remains to be investigated in future studies whether plant-based materials have some inherent qualities that make them more salient to pigs than non-plant materials. If such a generalised difference existed, it would explain why e.g. burlap sacks, another plant-based material, also have been found effective in reducing tail biting (Ursinus et al., 2014). However, another potential explanation for the attraction to plant-based materials could be that they usually are, to some extent, chewable, which is an important characteristic for pigs (van de Weerd et al., 2003). Beaudoin et al. (2019) found that pigs interacted frequently with non-plant, chewable polyurethane balls, spring-mounted on the floor. However, Beaudoin et al. (2019) also found that pigs spent more time interacting with a beam of cedar wood than with rubber objects, despite the latter being more chewable, suggesting a potential significance for the wood odour as well.

6.4 Additive effects of different materials

A previous study, testing combinations of distinctly different types of materials, such as metal chain combined with sawdust, showed additive effects (Guy et al., 2013). Some combinations of point-source objects have also shown promise in reducing tail biting (Chou et al., 2019). In one of the studies in this thesis, Study II, the experimental design included testing whether a combination of different objects would be more efficient in reducing tail and ear biting than each of those objects alone. The WPB treatment involved furnishing the pens with all of the objects used in the other experimental treatments: W (wooden logs), P (plastic pipe cross) and B (branching chain). While the WPB treatment did have significantly better efficacy in tail damage reduction than the control treatment, and in ear damage reduction than the B treatment, the WPB and W treatments did not differ from each other in efficacy. This suggests that the beneficial effect of the WPB treatment was an effect of the wood and that addition of plastic and metal objects, at least of the types and in the quantities used in this study, did not provide additional benefits.

Study III involved another kind of a combination of different materials: the type of continuously available objects affected the behavioural effects of a marginal provision of straw. After consuming the straw, oral-nasal manipulation of other pigs was less frequent in the experimental pens with continuous access to logs of recently harvested wood than in the control pens with continuous access to pieces of commercially sourced wood and complex metal chain. This difference between treatments was significant only after the provision of straw, not before. This may suggest that access to recently harvested wood enhanced the beneficial effects of the marginal provision of straw. A previous study has indicated that small quantities of straw alone are often not enough to generate such behavioural benefits: a study comparing 25, 50 and 100g of straw per pig per day found no difference in pig-directed oral-nasal manipulation (Amdi et al., 2015).

6.5 Outcomes related to production economy and feasibility

All the materials selected for testing in this study were selected on the basis that they would be compatible with slatted or partly slatted floors, which are by far the most common type of pen floors in commercial pig farming (rev. in Godyn et al., 2019). In such pens, manure and urine fall through the slats, are carried away via drainpipes, and the resulting mixture is managed as slurry.

As the drainpipes on many farms are narrow in diameter (often less than 30cm), any loose material that falls through the slats can block the drain or get tangled in the pumping equipment (rev. in Buijs and Muns, 2019). Therefore, one of the requirements for materials to be selected for this study was that there either were no loose parts that could fall through the slats, or that any particles that did fall through the slats would be small enough and decompose fast enough to avoid problems with manure management. Meeting of this requirement was verified by asking the farm owners and staff whether any such problems had occurred. The only problem that did occur was that in the post-weaning phase of Study I, the sisal ropes that we had furnished for the identical post-weaning environments of both treatment groups, had been suspended in a way that allowed the weaned piglets to bite off rope fibres of 10cm to 30cm in length, and some of these got tangled in the manure pump and stopped it from functioning. Ropes in the pre-weaning environment did not have this effect, so the likely explanation is that the biting force of pre-weaned piglets was not yet enough to sever any fibres from the ropes. This was confirmed by visual inspection of the ropes. By the age of eight weeks, several of the ropes in the growing pens had part of the length of the rope missing. This suggests that when natural fibre ropes are provided to pigs past weaning age on slatted or partly slatted floors, it is advisable to provide them in a way that only allows chewing at the end of the rope, so that any detached fibres will be only a few centimetres long.

The experimental treatments had no effects on piglet growth and mortality; nor on the numbers of finishing pigs removed from pens due to death, culling or transfer to hospital pens; nor on percentages of gilts approved as breeders; nor on pen hygiene. This finding suggests that the experimental treatments did not have adverse effects on these parameters, but on the other hand, it also suggests the experimental treatments may not have improved these production-relevant parameters. This is one of the aspects in which the object designs and materials tested still require further development (rev. in Buijs and Muns, 2019). It is paramount to develop improvements in pen environments that also improve production economics (rev. in van de Weerd and Day, 2009; rev. in van de Weerd and Ison, 2019), and do so substantially enough to cover, and preferably exceed, the material and labour costs. Otherwise, most farmers will not have an incentive, or indeed cannot afford, to adopt such improvements.

Several important production-related parameters were not investigated in the current studies. Some studies have found that providing pigs with supplementary objects has increased average daily weight gain (Hill et al., 1998; Casal-Plana et al., 2017). However, a meta-analysis of 45 experiments by Averós et al. (2010) did not find significant effects of the provided materials on average daily gain, average daily feed intake or feed conversion ratio. There also is evidence that meat quality is only marginally affected by pig welfare (Beattie et al., 2000). If the provision of improved materials for manipulation were to have effects of sufficient magnitude in reducing stress, including stress caused by being tail bitten, then it might be possible that these effects would partly offset the cost of providing the materials. Whether it is possible to develop objects that are efficient enough in this to offset their costs, remains to be investigated in future studies.

The estimated effects on productivity, based on the measured costs of materials and labour in these studies, are highly tentative and only apply on these farms; on these specific ways of using these materials; and on the cost structure of pig farming in Finland. They are presented here mainly in order to stimulate discussion on which economic parameters, and how, would be useful to include when studying materials and objects with the ultimate aim of developing solutions to be adopted on commercial farms.

6.6 Practical implications

The results of these studies showed that the materials and object designs, as well as the methods for attaching and dispensing them, were feasible in everyday life of commercial pig farms with partly slatted pen floors. No adverse effects on pig health or practicalities of production were observed (with the exception of the obstruction of the manure pump by the pieces bitten off the ropes in the post-weaning pens in Study I, which was a result of insufficiently detailed planning of on how to suspend the ropes in the weaner pens, but which does not affect the conclusions on the efficacy on pre-weaning materials). Regarding tail biting, the results showed that it is possible to reduce post-weaning tail biting by adding pre-weaning materials for manipulation, and that logs of recently harvested wood suspended horizontally can reduce tail biting, at least if there is a sufficient quantity of them. On the economics of production, the studies did not include measuring whether the interventions had beneficial effects on health or on growth rate from weaning to slaughter, and if they did, whether the economic benefit gained would be higher than the material and labour costs of providing the supplementary materials. In sum, while the studies showed the materials and designs tested are feasible in intensive farming and some of them bring welfare benefits, it is not yet known whether they would also bring economic benefits to the farmer.

The results presented in this thesis, including the estimates on economic consequences, are highly likely to be affected by several factors of farm design and management that will vary from farm to farm. Therefore, the results of this study are specific to these farms and will need replication on several different farms before drawing generalised conclusions. While some of the materials and objects did reduce tail biting, it is important to note that some tail biting still occurred in all treatment groups. This finding underscores a need to continue further development of the materials and designs tested, as well as to continue addressing all the other causal factors affecting this multifactorial problem. It is of fundamental importance to ensure that all communication about pig welfare includes clarity on not only the level of improvements that have attained, but also the level of further improvements needed before the behavioural needs of pigs, such as those for rooting and chewing, are genuinely met.

In general, scientific knowledge on behavioural needs and sentience of animals has advanced greatly during recent decades (rev. in Broom, 2010). One can safely assume that when the development of the current concept of intensive farming began, nearly a century ago, few of its early planners understood the severity of the problems it would cause to animals, such as thwarting most of their basic behavioural needs and inducing tail biting and other abnormal behaviours resulting in considerable pain. At present, intensive farming continues for a number of reasons, including low consumer prices for meat, leaving little room for farmers to improve the welfare of their animals. Any substantial improvements in pig welfare are likely to require not only added details in existing systems, such as materials for manipulation, but also collaboration between the scientific community and farming community to develop genuinely novel concepts of farming, in order to attain economically and environmentally viable ways to substantially improve animal welfare.

7. Conclusions

The severity of post-weaning tail biting was reduced by providing more materials for manipulation than the minimum required by EU legislation. The supplementary materials also reduced the re-direction of oral-nasal manipulation at other piglets, as compared to the levels seen in ordinary commercial farrowing conditions, but this effect did not persist after all the piglets were transferred to identical post-weaning environments. No adverse effects on growth or mortality were found. Further studies are required to determine which materials are the most effective and which is the minimum quantity of materials needed, both pre- and post-weaning, to attain this effect.

The prevalence of tail and ear biting in growing-finishing pigs was reduced by providing recently harvested wood suspended in a horizontal position, but an important factor may have been to have enough wood to allow simultaneous access to all or nearly all the pigs in the pen. Additional objects made of metal chain and plastic pipe did not provide added benefits, as compared to the effects of wooden objects alone. No adverse effects on morbidity and pen hygiene were found. Further studies are required to determine whether the results are replicable on commercial farms with varying baseline levels of tail biting.

Small amounts of recently harvested wood reduced the latency to approach an unfamiliar human and reduced ear biting. In another study, small amounts of recently harvested wood enhanced the capacity of marginal provisions of straw to reduce redirection of oral-nasal behaviours at other pigs, suggesting some welfare benefits. However, this small difference between treatments did not cause differences in the prevalence of tail biting. No adverse effects in the percentage of gilts approved as breeders were found. Further studies are required to determine the minimum quantity of wood needed to reduce tail biting and to optimise details such as log thickness, object design and locations in pens.

Polythene pipes attached to form a cross and suspended in a horizontal position elicited as much object-directed activity as recently harvested wood, but they did not reduce tail and ear biting. This finding suggests that the frequency of object interaction is an insufficient proxy measure for its efficacy in reducing tail biting.

The metal objects tested in the study did not bring any measurable welfare benefits, despite having been designed to include added structural complexity to sustain the interest of pigs.

Acknowledgements

The experimental studies were made possible by funding from the Ministry of Agriculture and Forestry of Finland. Writing of the peer-reviewed articles was supported by funding from the Finnish Veterinary Foundation. Writing of this thesis was supported by the University of Helsinki and by the Finnish Concordia Fund.

Other crucial contributors making these studies possible were the owners of the four commercial pig farms (who were given the right to remain anonymous), who had the courage to allow researchers in and test these new ideas.

I would also like to thank my supervisor Prof. Anna Valros for guidance and good discussions, as well as my other co-authors Kirsi Swan and Heikki Hirvonen at the University of Helsinki and Marc Bracke at the University of Wageningen in the Netherlands. All four have been a great pleasure to work with. Thanks are also due to the other colleagues at Helsinki University who provided practical assistance and companionship, Pälvi Palander and the late Antti Flyckt; as well as to the tireless students who assisted with data collection, Sara Holms and Marika Hakonen. The planning stage of the studies also benefited from fruitful discussions with Prof. Sandra Edwards of Newcastle University in the UK and Prof. Margit Bak Jensen at Aarhus University in Denmark, to whom I am also very thankful.

As always, the being there and the support of family is essential in any project like this, for which I also am deeply thankful.

Helena Telkänranta

December 2019

References

Amdi, C., Lahrmann, H. P., Oxholm, L. C., Schild, S.-L. A., Nielsen, M. B. F., Steinmetz, H. V., Hansen, C. F. 2015. Pen-mate directed behaviour in ad libitum fed pigs given different quantities and frequencies of straw. *Livestock Science* 171, 44–51.

Averós, X., Brossard, L., Dourmad, J.-Y., de Greef, K. H., Edge, H. L., Edwards, S. A., Meunier-Salaün, M.-C. 2010. A meta-analysis of the combined effect of housing and environmental enrichment characteristics on the behaviour and performance of pigs. *Applied Animal Behaviour Science* 127, 73–85.

Barnett, J. L., Hemsworth, P. H., Cronin, G. M., EJongman, E. C., Hutson, G. D. 2001. A review of the welfare issues for sows and piglets in relation to housing. *Australian Journal of Agricultural Research* 52, 1–28.

Baxter, E. M., Lawrence, A. B., Edwards, S. A. 2011. Alternative farrowing systems: design criteria for farrowing systems based on the biological needs of sows and piglets. *Animal* 5, 580–600.

Beattie, V., E., O'Connell, N. E., Moss, B. W. 2000. Influence of environmental enrichment on the behaviour, performance and meat quality of domestic pigs. *Livestock Production Science* 65, 71–79.

Beattie, V. E., Sneddon, I. A., Walker, N., Weatherup, R. N. 2001. Environmental enrichment of intensive pig housing using spent mushroom compost. *Animal Science* 72, 35–42.

Beaudoin, J.-M., Bergeron, R., Devillers, N., Laforest, J.-P. 2019. Growing pigs' interest in enrichment objects with different characteristics and cleanliness. *Animals* 9, 85.

Bench, C. J., Gonyou, H. W. 2006. Effect of environmental enrichment at two stages of development on belly nosing in piglets weaned at fourteen days. *Journal of Animal Science* 84, 3397–3403.

Bench, C. J., Gonyou, H. W. 2009. Ontogeny of belly nosing in pigs weaned at 14 days of age: A study from weaning to 13 weeks of age. *Canadian Journal of Animal Science* 89, 187–194.

Binderup, M.-L., Pedersen, G. A., Vinggaard, A. M., Rasmussen, E. S., Rosenquist, H., Cederberg, T. 2002. Toxicity testing and chemical analyses of recycled paper for food contact. *Food Additives and Contaminants* 19, 13–28.

Bolhuis, J. E., Schouten, W. G. P., de Leeuw, J. A., Schrama, J. W., Wiegant, V. A. 2004. Individual coping characteristics, rearing conditions and behavioural flexibility in pigs. *Behavioural Brain Research* 152, 351–360.

Bracke, M B. M., Zonderland, J. J., Lenskens, P., Schouten, W. G. P., Vermeer, H., Spoolder, H. A. M., Hendriks H. J. M., Hopster, H. 2006. Formalised review of environmental enrichment for pigs in relation to political decision making. *Applied Animal Behaviour Science* 98, 165–182.

Bracke, M B. M., Zonderland, J. J., Bleumer, E. J. B. 2006. Expert judgement on enrichment materials for pigs validates preliminary RICHPIG model. *Applied Animal Behaviour Science* 104, 1–13.

Bracke, M B. M. 2007. Multifactorial testing of enrichment criteria: Pigs 'demand' hygiene and destructibility more than sound. *Applied Animal Behaviour Science* 107, 218–232.

Bracke, M B. M., Spoolder, H. A. M. 2008. Novel object test can detect marginal differences in environmental enrichment in pigs. *Applied Animal Behaviour Science* 109, 39–48.

Bracke, M. B. M., Koene, P. 2019. Expert opinion on metal chains and other indestructible objects as proper enrichment for intensively-farmed pigs. *PLoS ONE* 14(2): e0212610.

Brand, M. A., de Muniz, G. I. B., Quirino, W. F., Brito, J. O. 2011. Storage as a tool to improve wood fuel quality. *Biomass and Bioenergy* 35, 2581–2588.

Broom, D. M. 2010. Cognitive ability and awareness in domestic animals and decisions about obligations to animals. *Applied Animal Behaviour Science* 126, 1–11.

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, 18–25.

Brunberg, E. I., Rodenburg, T. B., Rydhmer, L., Kjaer, J. B., Jensen, P., Keeling, L. J. 2016. Omnivores going astray: A review and new synthesis of abnormal behavior in pigs and laying hens. *Frontiers in Veterinary Science* 3, 57.

Buijs, S., Muns, R. 2019. A review of the effects of non-straw enrichment on tail biting in pigs. *Animals* 9, 824.

Bulens, A., van Beirendonck, S., van Thielen, J., Buys, N., Driessen, B. 2015. Straw applications in growing pigs: Effects on behavior, straw use and growth. *Applied Animal Behaviour Science* 169, 26–32.

Casal-Plana, N., Manteca, X., Dalmau, A., Fàbrega, E. 2017. Influence of enrichment material and herbal compounds in the behaviour and performance of growing pigs. *Applied Animal Behaviour Science* 195, 38–43.

Caselli, M., de Gennaro, G., Saracino, M. R., Tutino, M. 2009. Indoor contaminants from newspapers: VOCs emissions in newspaper stands. *Environmental Research* 109, 149–157.

Chaloupková, H., Illmann, G., Neuhauserová, K., Tomanek, M., Valis, L. 2007. Preweaning housing effects on behavior and physiological measures in pigs during the suckling and fattening periods. *Journal of Animal Science* 85, 1741–1749.

Chou, J.-Y., D'Eath, R., Sandercock, D. A., Waran, N., Haigh, A., O'Driscoll, K. 2018. Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system. *Livestock Science* 213, 19–27.

Chou, J.-Y., Drique, C. M. V., Sandercock, D. A., D'Eath, R., O'Driscoll, K. 2019. Rearing undocked pigs on fully slatted floors using multiple types and variations of enrichment. *Animals* 9, 139.

Cornale, P., Macchi, E., Miretti, S., Renna, M., Lussian, C., Peron, G., Mimosi, A. 2015. Effects of stocking density and environmental enrichment on behavior and fecal corticosteroid levels of pigs under commercial farm conditions. *Journal of Veterinary Behavior* 10, 569–576.

Day, J. E. L., Burfoot, A., Docking, C. M., Whittaker, X., Spoolder, H. A. M., Edwards, S. A. 2002. The effects of prior experience of straw and the level of straw provision on the behaviour of growing pigs. *Applied Animal Behaviour Science* 76, 189–202.

Day, J. E. L., van de Weerd, H. A., Edwards, S. A. 2008. The effect of varying lengths of straw bedding on the behaviour of growing pigs. *Applied Animal Behaviour Science* 109, 249–260.

de Jong, I. C., Prelle, I. T., van de Burgwal, J. A., Lambooij, E., Korte, S. M., Blokhuis, H. J., Koolhaas, J. M. 2000. Effects of environmental enrichment on behavioral responses to novelty, learning, and memory, and the circadian rhythm in cortisol in growing pigs. *Physiology & Behavior* 68, 571–578.

de Jonge, F. H. Bokkers, E. A. M., Schouten, W. G. P., Helmond, F. A. 1996. Rearing piglets in a poor environment: Developmental aspects of social stress in pigs. *Physiology & Behavior* 60, 389–396.

D'Eath, R. B., Arnott, G., Turner, S. P., Jensen, T., Lahrmann, H. P., Busch, M. E., Niemi, J. K., Lawrence, A. B., Sandøe, P. 2014. Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? *Animal* 8, 1479–1497.

D'Eath, R., Niemi, J. K., Ahmadi, B. V., Rutherford, K. M. D., Ison, S. H., Turner, S. P., Anker, H. T., Jensen, T., Busch, M. E., Jensen, K. K., Lawrence, A. B., Sandøe, P. 2016. Why are most EU pigs tail docked? Economic and ethical analysis of four pig housing and management scenarios in the light of EU legislation and animal welfare outcomes. *Animal* 10, 687–699.

Di Giminiani, P., Edwards, S. A., Malcolm, E. M., Leach, M. C., Herskin, M. S., Sandercock, D. A. 2017. Characterization of short- and long-term mechanical sensitisation following surgical tail amputation in pigs. *Scientific Reports* 7, 4827.

Di Giminiani, P., Nasirahmadi, A., Malcolm, E. M., Leach, M. C., Edwards, S. A. 2017. Docking piglet tails: How much does it hurt and for how long? *Physiology & Behavior* 182, 69–76.

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.

Docking, C. M., van de Weerd, H. A., Day, J. E. L., Edwards, S. A. 2008. The influence of age on the use of potential enrichment objects and synchronisation of behaviour of pigs. *Applied Animal Behaviour Science* 110, 244–257.

Douglas, C., Bateson, M., Walsh, C., Béduéc, A., Edwards, S. A. 2012. Environmental enrichment induces optimistic cognitive biases in pigs. *Applied Animal Behaviour Science* 139, 65–73.

Douglas, S. L., Szyszka, O., Stoddart, K., Edwards, S. A., Kyriazakis, I. 2015. Animal and management factors influencing grower and finisher pig performance and efficiency in European systems: a meta-analysis. *Animal* 9, 1210–1220.

European Union 2008. Council Directive 2008/120/EC laying down minimum standards for the protection of pigs. EUR-Lex https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0120 Referenced: 17 December 2019.

Fàbrega, E., Marcet-Rius, M., Vidal, R., Escribano, D., Cerón, J. J., Manteca, X., Velarde, A. 2019. The Effects of environmental enrichment on the physiology, behaviour, productivity and meat quality of pigs raised in a hot climate. *Animals* 9, 235.

FAO, the Food and Agriculture Organisation of the United Nations. 2019. FAO Agri-Environmental Indicators Update: Livestock. 24 April 2019. Patternshttp://www.fao.org/economic/ess/environment/data/livestock-patterns/en/ Referenced: 17 December 2019.

Finland's Ministry of Justice 2002. Valtioneuvoston asetus eläinsuojeluasetuksen muuttamisesta. Finlex Data Bank, https://www.finlex.fi/fi/laki/alkup/2002/20020910 Referenced: 25 December 2019.

Finland's Ministry of Justice 2017. Valtioneuvoston asetus sikojen suojelusta annetun valtioneuvoston asetuksen muuttamisesta. Finlex Data Bank, https://www.finlex.fi/fi/laki/alkup/2017/20170154 Referenced: 18 December 2019.

Fureix, C., Meagher, R. K. 2015. What can inactivity (in its various forms) reveal about affective states in non-human animals? A review. *Applied Animal Behaviour Science* 171, 8–24.

Gifford, A. K., Cloutier, S., Newberry, R. C. 2007. Objects as enrichment: Effects of object exposure time and delay interval on object recognition memory of the domestic pig. *Applied Animal Behaviour Science* 107, 206–217.

Godyn, D., Nowicki, J., Herbut, P. 2019. Effects of environmental enrichment on pig welfare – A review. *Animals* 9, 383.

Graves, H. B. 1984. Behavior and ecology of wild and feral swine (Sus scrofa). *Journal of Animal Science* 58, 482–492.

Guy, J. H., Meads, Z. A., Shiel, R. S., Edwards, S. A. 2013. The effect of combining different environmental enrichment materials on enrichment use by growing pigs. *Applied Animal Behaviour Science* 144, 102–107.

Herskin, M. S., Jensen, H. E., Jespersen, A., Forkman, B., Jensen, M. B., Canibe, N., Pedersen, L. J. 2016. Impact of the amount of straw provided to pigs kept in intensive production conditions on the occurrence and severity of gastric ulceration at slaughter. *Research in Veterinary Science* 104, 200–206.

Hill, J. D., McGlone, J. J., Fullwood, S. D., Miller, M. F. 1998. Environmental enrichment influences on pig behavior, performance and meat quality. *Applied Animal Behaviour Science* 57, 51–68.

Hötzel, M. J., Machado, L. C. P., Wolf, F. M., Dalla Costa, O. A. 2004. Behaviour of sows and piglets reared in intensive outdoor or indoor systems. *Applied Animal Behaviour Science* 86, 27–39.

Jensen, M. B., Pedersen, L. J. 2008. Using motivation tests to assess ethological needs and preferences. *Applied Animal Behaviour Science* 113, 340–356.

Jensen, M. B., Herskin, M. S., Forkman, B., Pedersen, L. J. 2015. Effect of increasing amounts of straw on pigs' explorative behaviour. *Applied Animal Behaviour Science* 171, 58–63.

Jensen, P., Toates, F. M. 1993. Who needs behavioural needs? Motivational aspects of the needs of animals. *Applied Animal Behaviour Science* 37, 161–181.

Korte, S. M., Olivier, B., Koolhaas, J. M. 2007. A new animal welfare concept based on allostasis. *Physiology & Behavior* 92, 422–428.

Kritas, S. K., Morrison, R. B., 2004. An observational study on tail biting in commercial grower-finisher barns. *Journal of Swine Health and Production* 12, 17–22.

Lahrmann, H. P., Oxholm, L. C., Steinmetz, H., Nielsen, M. B. F., D'Eath, R. B. 2015. The effect of long or chopped straw on pig behaviour. *Animal* 9, 862–870.

Lahrmann, H. P., Hansen, C. F., D´Eath, R. B., Busch, M. E., Nielsen, J. P., Forkman, B. 2018. Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs. *Livestock Science* 214, 272–277.

Lahrmann, H. P., Faustrup, J. F., Hansen, C. F., D´Eath, R. B., Nielsen, J. P., Forkman, B. 2019. The effect of straw, rope, and Bite-Rite treatment in weaner pens with a tail biting outbreak. *Animals* 9, 365.

Larsen, M. L. V., Andersen, H. M.-L., Pedersen, L. J. 2016. Can tail damage outbreaks in the pig be predicted by behavioural change? *The Veterinary Journal* 209, 50–56.

Larsen, M. L. V., Andersen, H. M.-L., Pedersen, L. J. 2018. Which is the most preventive measure against tail damage in finisher pigs: tail docking, straw provision or lowered stocking density? *Animal* 12, 1260–1267.

Larsen, M. L. V., Jensen, M. B., Pedersen, L. J. 2019. Increasing the number of wooden beams from two to four increases the exploratory behaviour of finisher pigs. *Applied Animal Behaviour Science* 216, 6–14.

Laskoski, F., Faccin, J. E. G., De Conti, E. R., Mellagi, A. P., Ulguim, R., Bortolozzo, F. 2019. Effects of proportion of pigs per feeder hole and stocking density on growth performance and tail and ear biting in the nursery. *Journal of Animal Science* 97, S2, 168.

Lewis, E., Boyle, L. A., O'Doherty, J. V., Lynch, P. B., Brophy, P. 2006. The effect of providing shredded paper or ropes to piglets in farrowing crates on their behaviour and health and the behaviour and health of their dams. *Applied Animal Behaviour Science* 96, 1–17.

Luo, L., Reimert, I., de Haas, E. N., Kemp, B., Bolhuis, J. E. 2019. Effects of early and later life environmental enrichment and personality on attention bias in pigs (Sus scrofa domesticus). *Animal Cognition* 22, 959–972.

Mayer, J. J., Martin, F. D., Brisbin Jr., I. L. 2002. Characteristics of wild pig farrowing nests and beds in the upper Coastal Plain of South Carolina. Applied Animal Behaviour Science 78, 1–17.

Meunier-Salaun, M. C., Bizeray, D., Colson, V., Courboulay, V., Lensink, J., Prunier, A., Remience, V., Vandenheede, M. 2007. The welfare of farmed pigs. *Productions Animales* 20, 73–80.

Moinard, C., Mendl, M., Nicol, C. J., Green, L. E. 2003. A case control study of on-farm risk factors for tail biting in pigs. *Applied Animal Behaviour Science* 81, 333–355.

Munsterhjelm, C., Peltoniemi, O. A. T., Heinonen, M., Hälli, O., Karhapää, M., Valros, A. 2009. Experience of moderate bedding affects behaviour of growing pigs. *Applied Animal Behaviour Science* 118, 42–53.

Munsterhjelm, C., Valros, A., Heinonen, M., Hälli, O., Siljander-Rasi, H., Peltoniemi, O. A. T. 2010. Environmental enrichment in early life affects cortisol patterns in growing pigs. *Animal* 4, 242–249.

Munsterhjelm, C., Brunberg, E., Heinonen, M., Keeling, L., Valros, A. 2013. Stress measures in tail biters and bitten pigs in a matched case-control study. *Animal Welfare* 22, 331–338.

Munsterhjelm, C., Heinonen, M., Valros, A. 2015. Application of the Welfare Quality (R) animal welfare assessment system in Finnish pig production, part II: Associations between animal-based and environmental measures of welfare. *Animal Welfare* 24, 161–172.

Möttönen, V. 2006. Variation in drying behavior and final moisture content of wood during conventional low temperature drying and vacuum drying of Betula pendula timber. *Drying Technology* 24, 1405–1413.

Nannoni, E., Valsami, T., Sardi, L., Martelli, G. 2014. Tail docking in pigs: a review on its short- and long-term consequences and effectiveness in preventing tail biting. *Italian Journal of Animal Science* 13, 3095.

Nannoni, E., Sardi, L., Vitali, M., Trevisi, E., Ferrari, A., Barone, F., Bacci, M. L., Barbieri, S., Martelli, G. 2016. Effects of different enrichment devices on some welfare indicators of post-weaned undocked piglets. *Applied Animal Behaviour Science* 184, 25–34.

Nawroth, C., Langbein, J., Coulon, M., Gabor, V., Oesterwind, S., Benz-Schwarzburg, J., von Borell, E. 2019. Farm animal cognition – Linking behavior, welfare and ethics. *Frontiers in Veterinary Science* 6, 24.

Nielsen, B. L., Jezierski, T., Bolhuis, J. E., Amo, L., Rosell, F., Oostindjer, M., Christensen, J. W., McKeegan, D., Wells, D. L., Hepper, P. 2015. Olfaction: an overlooked sensory modality in applied ethology and animal welfare. *Frontiers in Veterinary Science* 2, 69.

Oxholm, L. C., Steinmetz, H. V., Lahrmann, H. P., Nielsen, M. B. F., Amdi, C., Hansen, C. F. 2014. Behaviour of liquid-fed growing pigs provided with straw in various amounts and frequencies. *Animal* 8, 1889–1897.

Peden, R. S. E., Turner, S. P., Boyle, L. A., Camerlink, I. 2018. The translation of animal welfare research into practice: The case of mixing aggression between pigs. Applied Animal Behaviour Science 204, 1–9.

Pedersen, L. J., Herskin, M. S., Forkman, B., Halekoh, U., Kristensen, K. M., Jensen, M. B., 2014. How much is enough? The amount of straw necessary to satisfy pigs' need to perform exploratory behaviour. *Applied Animal Behaviour Science* 160, 46–55.

Reimert, I., Rodenburg, T. B., Ursinus, W. W., Kemp, B., Bolhuis, J. E. 2014. Responses to novel situations of female and castrated male pigs with divergent social breeding values and different backtest classifications in barren and straw-enriched housing. *Applied Animal Behaviour Science* 151, 24–35.

Sandercock, D. A., Smith, S. H., Di Giminiani, P., Edwards, S. A. 2016. Histopathological characterization of tail injury and traumatic neuroma development after tail docking in piglets. *Journal of Comparative Pathology* 155, 40–49.

Schrøder-Petersen, D. L., Heiskanen, T., Ersbøll, A. K. 2004. Tail-in-mouth behaviour in slaughter pigs, in relation to internal factors such as: age, size, gender, and motivational background. *Acta Agriculturae Scandinavica, Section A — Animal Science,* 54, 159–166.

Scott, K., Taylor, L., Gill, B. P., Edwards, S. A. 2007. Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems 2. Ratio of pigs to enrichment. *Applied Animal Behaviour Science* 105, 51–58.

Sinisalo, A., Niemi, J. K., Heinonen, M., Valros, A. 2012. Tail biting and production performance in fattening pigs. *Livestock Science* 143, 220–225.

Smulders, D., Hautekiet, V., Verbeke, G., Geers, R. 2008. Tail and ear biting lesions in pigs: an epidemiological study. *Animal Welfare* 17, 61–69.

Špinka, M. 2006. How important is natural behaviour in animal farming systems? *Applied Animal Behaviour Science* 100, 117–128.

Statham, P., Green, L., Mendl, M. 2011. A longitudinal study of the effects of providing straw at different stages of life on tail-biting and other behaviour in commercially housed pigs. *Applied Animal Behaviour Science* 134, 100–108.

Stolba, A., Wood-Gush, D. G. M. 1989. The behaviour of pigs in a semi-natural environment. *Animal Production* 48, 419–425.

Studnitz, M., Jensen, K. H., Jørgensen, E. 2003. The effect of nose rings on the exploratory behaviour of outdoor gilts exposed to different tests. *Applied Animal Behaviour Science* 84, 41–57.

Studnitz, M., Jensen, M. B., Pedersen, L. J. 2007. Why do pigs root and in what will they root? A review on the exploratory behaviour of pigs in relation to environmental enrichment. *Applied Animal Behaviour Science* 107, 183–197.

Swan K.-M., Telkänranta, H., Munsterhjelm, C., Peltoniemi, O., Valros, A. 2017. Access to chewable materials increases piglet activity during lactation. *Proceedings of the 11th International Veterinary Behaviour Meeting,* 14-16th September 2017, Samorin, Slovakia.

Tarou, L. R., Bashaw, M. J. 2007. Maximizing the effectiveness of environmental enrichment: Suggestions from the experimental analysis of behaviour. *Applied Animal Behaviour Science* 102, 189–204.

Taylor, N. R., Main, D. C. J., Mendl, M., Edwards, S. A. 2010. Tail-biting: A new perspective. *The Veterinary Journal* 186, 137–147.

Taylor, N. R., Parker, R. M. A., Mendl, M., Edwards, S. A., Main, D. C. J. 2012. Prevalence of risk factors for tail biting on commercial farms and intervention strategies. *The Veterinary Journal* 194, 77–83.

Telkänranta, H. and Edwards, S. A. 2018. Lifetime consequences of the early physical and social environment of piglets. In Spinka, M. (ed.): *Advances in Pig Welfare,* Elsevier.

Trickett, S. L., Guy, J. H., Edwards, S. A. 2009. The role of novelty in environmental enrichment for the weaned pig. *Applied Animal Behaviour Science* 116, 45–51.

Tuyttens, F. A. M. 2005. The importance of straw for pig and cattle welfare: A review. *Applied Animal Behaviour Science* 92, 261–282.

Tönepöhl, B., Appel, A. K., Welp, S., Voss, B., von Borstel, U. K., Gauly, M. 2012. Effect of marginal environmental and social enrichment during rearing on pigs' reactions to novelty, conspecifics and handling. *Applied Animal Behaviour Science* 140, 137–145.

Ursinus, W W., Wijnen, H. J., Bartels, A. C., Dijvesteijn, N., van Reenen, C. G., Bolhuis, J. E. 2014. Damaging biting behaviors in intensively kept rearing gilts: The effect of jute sacks and relations with production characteristics. *Journal of Animal Science* 92, 5193–5202.

Valros, A. Munsterhjelm, C., Hänninen, L., Kauppinen, T. and Heinonen, M. 2016. Managing undocked pigs – on-farm prevention of tail biting and attitudes towards tail biting and docking. *Porcine Health Management* 2, 2.

Valros, A. 2018. Tail biting. In Spinka, M. (ed.): *Advances in Pig Welfare,* Elsevier.

van de Perre, V., Driessen, B., van Thielen, J., Verbeke, G., Geers, R. 2011. Comparison of pig behaviour when given a sequence of enrichment objects or a chain continuously. *Animal Welfare* 20, 641–649.

van de Weerd, H. A., Docking, C. M., Day, J. E. L., Avery, P. J., Edwards, S. A. 2003. A systematic approach towards developing environmental enrichment for pigs. *Applied Animal Behaviour Science* 84, 101–118.

van de Weerd, H. A., Docking, C. M., Day, J. E. L., Edwards, S. A. 2005. The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. *Animal Science* 80, 289–298.

van de Weerd, H. A., Docking, C. M., Day, J. E. L., Breuer, K., Edwards, S. A. 2006. Effects of species-relevant environmental enrichment on the behaviour and productivity of finishing pigs. *Applied Animal Behaviour Science* 99, 230–247.

van de Weerd, H. A., Day, J. E. L. 2009. A review of environmental enrichment for pigs housed in intensive housing systems. *Applied Animal Behaviour Science* 116, 1–20.

van de Weerd, H. A., Ison, S. 2019. Providing effective environmental enrichment to pigs: how far have we come? *Animals* 9, 254.

van Staaveren, N., Hanlon, A., Boyle, L. A. 2019. Damaging behaviour and associated lesions in relation to types of enrichment for finisher pigs on commercial farms. *Animals* 9, 677.

Vanheukelom, V., Driessen, B., Maenhout, D., Geers, R. 2011. Peat as environmental enrichment for piglets: The effect on behaviour, skin lesions and production results. *Applied Animal Behaviour Science* 134, 42–47.

Vanheukelom, V., Driessen, B., Geers, R. 2012. The effects of environmental enrichment on the behaviour of suckling piglets and lactating sows: A review. *Livestock Science* 143, 116–131.

Weary, D. M., Droege, P., Braithwaite, V. A. 2017. Behavioral evidence of felt emotions: approaches, inferences, and refinements. *Advances in the Study of Behavior,* 49, 27–48.

Yang, C.-H., Ko, H.-L., Salazar, L. C., Llonch, L., Xavier Manteca, X., Camerlink, I., Llonch, P. 2018. Pre-weaning environmental enrichment increases piglets' object play behaviour on a large scale commercial pig farm. *Applied Animal Behaviour Science* 202, 7–12.

Yin, G. A., Li, X., Liu, H. G., Huang, D. P., Jun, B. 2014. Small quantities of straw provided daily improve behavior of growing gilts. *International Journal of Applied Research in Veterinary Medicine* 12, 54–60.

Zonderland, J. J., Wolthuis-Fillerup, M., van Reenen, C. G., Bracke, M. B. M., Kemp, B., den Hartog, L. A., Spoolder, H. A. M. 2008. Prevention and treatment of tail biting in weaned piglets. *Applied Animal Behaviour Science* 110, 269–281.

Zwicker, B., Gygax, L., Wechsler, B., Weber, R. 2013. Short- and long-term effects of eight enrichment materials on the behaviour of finishing pigs fed ad libitum or restrictively. *Applied Animal Behaviour Science* 144, 31–38.

Zwicker, B., Weber, R., Wechsler, B., Gygax, L. 2015. Degree of synchrony based on individual observations underlines the importance of concurrent access to enrichment materials in finishing pigs. *Applied Animal Behaviour Science* 172, 26–32.