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Welfare of pigs at slaughter

EFSA Panel on Animal Health and Welfare (AHAW),
Søren Saxmose Nielsen, Julio Alvarez, Dominique Joseph Bicout, Paolo Calistri, Klaus Depner, Julian Ashley Drewe, Bruno Garin-Bastuji, Jose Luis Gonzales Rojas, Christian Gortázar Schmidt, Virginie Michel, Miguel Ángel Miranda Chueca, Helen Clare Roberts, Liisa Helena Sihvonen, Hans Spoolder, Karl Stahl, Arvo Viltrop, Christoph Winckler, Denise Candiani, Chiara Fabris, Yves Van der Stede and Antonio Velarde

Abstract

The killing of pigs for human consumption (slaughtering) can take place in a slaughterhouse or on farm. The processes of slaughtering that were assessed for welfare, from the arrival of pigs until their death, were grouped into three main phases: pre-stunning (including arrival, unloading from the truck, lairage, handling and moving of pigs); stunning (including restraint); and bleeding. Stunning methods were grouped into three categories: electrical, controlled atmosphere and mechanical. Twelve welfare consequences the pigs can be exposed to during slaughter were identified: heat stress, cold stress, fatigue, prolonged thirst, prolonged hunger, impeded movement, restriction of movements, resting problem, negative social behaviour, pain, fear and respiratory distress. Welfare consequences and relevant animal-based measures were described. In total, 30 welfare hazards that could occur during slaughter were identified and characterised, most of them related to stunning and bleeding. Staff were identified as the origin of 29 hazards, which were attributed to the lack of appropriate skill sets needed to perform tasks or to fatigue. Corrective and preventive measures for these hazards were assessed: measures to correct hazards were identified, and management was shown to have a crucial role in prevention. Outcome tables linking hazards, welfare consequences, animal-based measures, origins and preventive and corrective measures were developed for each process. Mitigation measures to minimise welfare consequences are proposed.

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Keywords: pig, slaughter, hazards, animal welfare consequences, animal-based measures, preventive/corrective measures

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Correspondence: alpha@efsa.europa.eu

Panel members: Julio Alvarez, Dominique Joseph Bicout, Paolo Calistri, Klaus Depner, Julian Ashley Drewe, Bruno Garin-Bastuji, Jose Luis Gonzales Rojas, Christian Gortázar Schmidt, Miguel Ángel Miranda Chueca, Virginie Michel, Søren Saxmose Nielsen, Helen Clare Roberts, Liisa Helena Sihvonen, Hans Spoolder, Karl Stahl, Antonio Velarde, Arvo Viltrop and Christoph Winckler.

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Summary

In 2009, the European Union (EU) adopted Council Regulation (EC) No 1099/2009 'on the protection of animals at the time of killing', which was prepared on the basis of two scientific opinions adopted by the European Food Safety Authority (EFSA) in 2004 and 2006. In 2013, EFSA produced another scientific opinion related to this subject.

In parallel, since 2005, the World Organisation for Animal Health (OIE) has developed two chapters in its Terrestrial Animal Health Code: (i) Slaughter of animals (Chapter 7.5), (ii) Killing of animals for disease control purposes (Chapter 7.6). OIE has created an ad hoc working group to revise these two chapters.

Against this background, the European Commission requested EFSA to write a scientific opinion providing an independent view on the slaughter of pigs.

With specific reference to arrival of the pigs, unloading, lairage, handling and moving to the stunning point restraint, stunning, bleeding, emergency slaughter and methods, procedures or unacceptable practices on welfare grounds, EFSA was asked to: identify the animal welfare hazards and their possible origins in terms of facilities/equipment and staff (Term of Reference (ToR)-1); define qualitative or measurable criteria to assess performance on animal welfare (animal-based measures (ABMs)) (ToR-2); provide preventive and corrective measures (structural or managerial) to address the hazards identified (ToR-3); and point out specific hazards related to types of animal (e.g. young ones, etc.) (ToR-4). In addition, the European Commission asked EFSA to provide measures to mitigate the negative consequences on the welfare (so called 'welfare consequences') that can be caused by the identified hazards.

This scientific opinion aims at updating the above reported EFSA outputs by reviewing the most recent scientific publications and providing the European Commission with a sound scientific basis for future discussions at international level on the welfare of pigs in the context of slaughter.

The mandate also requested a list of unacceptable methods, procedures or practices that need to be analysed in terms of the above welfare aspects. It has to be noted that methods, procedures or practices cannot be subjected to a risk assessment procedure if there is no published scientific evidence related to them. Chapter 7.5.10 of the OIE Terrestrial Animal Health Code includes a list of several unacceptable practices and the Panel agrees with this list. In addition, the Panel listed some practices that lead to serious welfare concerns. These practices should be avoided, re-designed or replaced by other practices, leading to better welfare outcomes.

Council Regulation (EC) No. 1099/2009 defines slaughtering as 'the killing of animals intended for human consumption' and the related operations are 'operations that take place in the context and at the location where the animals are slaughtered.' This opinion concerns the killing of pigs for human consumption that takes place at slaughterhouse or during on-farm slaughter. In the context of this opinion, each related operation is a process, and several related operations (processes) are grouped in phases. The phases that have been assessed in this opinion, from arrival until the animal is dead, are: Phase 1 – pre-stunning, Phase 2 – stunning and Phase 3 – bleeding. Phase 1 includes (in chronological order): (a) arrival, (b) unloading of animals from the truck, (c) lairage and (d) handling and moving to the stunning area. Because restraint prior to stunning varies depending on the stunning method, restraint is assessed as a part of the relevant stunning method (Phase 2). The bleeding phase (Phase 3) includes exsanguination following stunning.

To address the mandate, three main sources of information were used in developing this opinion: (i) literature search and (ii) consultation of Member States (MSs) representatives, followed by (iii) expert opinion through working group (WG) discussion. The literature search was carried out to identify peer-reviewed scientific evidence providing information on the elements requested by the ToRs (i.e. description of the processes, identification of welfare hazards and their origin, preventive and corrective measures, welfare consequences and related ABMs) on the topic of slaughter of pigs (killing of pigs for human consumption). During the 2019 meeting of the representatives of the EU MSs' organisations designated as National Contact Points (NCPs) for Council Regulation (EC) No. 1099/2009 (NCPs Network meeting), hazards pertaining to each process of slaughtering were identified and discussed to gather information on which are most common in EU and are considered by national authorities as the most urgent to be addressed in order to safeguard animal welfare during the slaughtering of pigs.

From the available literature, their own knowledge and the results of the discussion with the NCPs Network, the WG experts identified the processes that should be included in the assessment and produced a list containing the possible welfare hazards of each process related to the slaughter of

pigs. To address the ToRs, experts identified the origin of each hazard (ToR-1) and related preventive and corrective measures (ToR-3), along with the possible welfare consequences of the hazards and relevant ABMs (ToR-2). Measures to mitigate the welfare consequences were also considered. Specific hazards were identified in the case of certain categories of pigs (ToR-4). In addition, uncertainty analysis on the hazard identification was carried out, but limited to quantification of the probability of occurrence of false-positive (included but non-existent) or false-negative (existing and not-included) hazards.

As this opinion will be used by the European Commission to address the OIE standards, more methods for slaughter than those reported in Council Regulation (EC) No. 1099/2009 have been considered. However, among the methods that are used worldwide, the following criteria have been applied for the selection of those included in this assessment: (a) all methods with described technical specifications known to the experts, not only those described in Council Regulation (EC) No. 1099/2009, and (b) methods currently used for slaughter of pigs as well as those still in development but likely to become commercially applicable and (c) methods for which the welfare aspects (in terms of welfare hazards, welfare consequences, ABMs, preventive and corrective measures) are described sufficiently in the scientific literature. Applying these criteria, some methods that may be applied worldwide have not been included in the current assessment.

The stunning methods that have been identified as relevant for pigs can be grouped in three categories: (1) electrical, (2) controlled atmospheres and (3) mechanical.

Electrical methods include head-only and head-to-body. Controlled atmosphere stunning methods (CAS) include carbon dioxide (CO_2) at high concentration (defined in this opinion as higher than 80% by volume), inert gases and CO_2 associated with inert gases. The mechanical methods that have been described in this report are captive bolt, percussive blow to the head and firearm with free projectile. These methods are mainly used as backup method or for small-scale slaughtering as in small abattoirs or on-farm slaughter. Because of the diversity of available stunning methods, this opinion will consider the assessment of welfare consequences, hazards, related animal-based measures (ABMs) and mitigation measures, origin of hazards and preventive/corrective actions for each method. For each process related to slaughter, a description on how it is technically and practically carried out is provided. In addition, the relevant welfare consequences and ABMs are identified (ToR-2). A list of the main hazards associated with the relevant welfare consequences is provided (ToR-1).

Twelve welfare consequences have been identified: heat stress, cold stress, fatigue, prolonged thirst, prolonged hunger, impeded movement, restriction of movements, resting problem, negative social behaviour, pain, fear and respiratory distress. Pigs experience welfare consequences due to the presence of hazards only when they are conscious, which applies to all pigs during the pre-stunning phase. In the stunning phase, pigs may experience welfare consequences if hazards occur during restraint (before stunning), if induction of unconsciousness is not immediate, or if stunning is ineffective. During bleeding following stunning, pigs will experience welfare consequences in cases of persistence of consciousness or if they recover consciousness after stunning and before death.

The mandate also asked for definitions of qualitative or measurable (quantitative) criteria to assess performance (i.e. consequences) on animal welfare (ABMs; ToR-2); this ToR was addressed by identifying the welfare consequences occurring to pigs and the relevant ABMs that can be used to assess qualitatively or quantitatively these welfare consequences. List and definitions of ABMs to be used for assessing the welfare consequences have been provided in this Opinion. ABMs for the assessment of all the welfare consequences have been identified, except for prolonged hunger and prolonged thirst at the time of arrival. However, under certain circumstances, not all the ABMs can be used because of low feasibility (e.g. at arrival/during lairage due to the lack of accessibility to the animals in the truck). Even if welfare consequences cannot be assessed during the slaughter of pigs, it does not imply they do not exist. It is to be noted that ABMs during stunning are the signs of consciousness, since consciousness is the prerequisite for animals to experience pain and fear during stunning. These ABMs of consciousness are specific to the stunning methods and were proposed in a previous EFSA opinion (EFSA AHAW Panel, 2013). Flowcharts, including ABMs of consciousness to be used for monitoring of stunning efficacy, are reproduced in this opinion in order to provide the European Commission with the full welfare assessment at slaughter.

In answering ToR-1, 30 related hazards to the previous welfare consequences were identified, from arrival of the pigs at the slaughter plant until they are dead. Some of these hazards were common to different phases. All the processes described in this opinion have hazards; regarding the stunning methods, some hazards related to the induction phase to unconsciousness (CAS), others to the restraint of pigs (i.e. electrical and mechanical methods). The main hazards are associated with lack of staff skills and training, and poor-designed and constructed facilities.

Animal welfare consequences can be the result of one or more hazards. Exposure to multiple hazards has a cumulative effect on the welfare consequences (e.g. pain due to injury caused at arrival will lead to more severe pain during unloading). Some hazards are inherent to the stunning method and cannot be avoided (e.g. restraining), other hazards originate from suboptimal application of the method, mainly due to unskilled staff (e.g. rough handling, use of wrong parameters e.g. for electrical methods). In fact, most of the hazards (29) had staff as origin, and hazards could be attributed to lack of appropriate skill sets needed to perform tasks or to fatigue.

The uncertainty analysis on the set of hazards provided for each process in this opinion revealed that the experts were 95–99% certain that all listed hazards occur during slaughter of pigs. However, the experts were 90–95% certain that at least one hazard was missing in the assessment considering the three criteria for the inclusion of methods and practices in this assessment. The three criteria are: a. all methods known to the experts that have technical specifications, b. methods currently used for slaughter of pigs and c. methods for which the welfare aspects are sufficiently described in the scientific literature.

Furthermore, in a global perspective, the experts were 95–99% certain that at least one welfare hazard was missing. This is due to the lack of documented evidence on all possible variations in the processes and methods being practised (see Interpretation of ToRs on the criteria for selection of stunning/killing methods to be included).

In response to ToR-3, preventive and corrective measures for the identified hazards have been identified and described. Some are specific for a hazard; others can apply to multiple hazards (e.g. staff training and rotation). For all the hazards, preventive measures can be put in place with management having a crucial role in prevention. Corrective measures were identified for 24 hazards; when they are not available or feasible to put in place, actions to mitigate the welfare consequences caused by the identified hazards should be put in place.

Finally, outcome tables summarising all the mentioned elements requested by the ToRs (identification of welfare hazards, origin, preventive and corrective measures, welfare consequences and related ABMs) have been produced for each process in the slaughter of pigs to provide an overall outcome, where all retrieved information is presented concisely. Conclusions and recommendations are provided subdivided for specific processes of slaughter.

To spare pigs from severe welfare consequences, a standard operating procedure (SOP) should include identification of hazards and related welfare consequences, using relevant ABMs, as well as preventive and corrective measures. At arrival, pigs should be unloaded as soon as possible and those with severe pain, signs of illness or those unable to move independently should be inspected and a procedure for emergency slaughter should be applied immediately. Keeping pigs in lairage should be avoided, unless it benefits their welfare. Permanent access to water, adequate space and protection from adverse weather conditions should always be ensured during lairage. Stunning methods that require painful restraint or induction of unconsciousness should not be used. To monitor stunning method efficacy, the state of consciousness of the animals should be checked immediately after stunning, just prior to neck cutting and during bleeding. Death must be confirmed before carcass processing begins.

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

1.1.1. Background

The European Union adopted in 2009 Council Regulation (EC) No 1099/2009[1] on the protection of animals at the time of killing. This piece of legislation was prepared based on two EFSA opinions respectively adopted in 2004[2] and 2006[3]. The EFSA provided additional opinions related to this subject in 2012[4], 2013[5,6,7,8,9,10], 2014[11,12], 2015[13] and 2017[14,15].

In parallel, since 2005, the World Organisation for Animal Health (OIE) has developed in its Terrestrial Animal Health Code two chapters covering a similar scope:

- Slaughter of animals (Chapter 7.5)
- Killing of animals for disease control purposes (Chapter 7.6)

The chapter slaughter of animals covers the following species: cattle, buffalo, bison, sheep, goats, camelids, deer, horses, pigs, ratites, rabbits and poultry (domestic birds as defined by the OIE).

The OIE has created an ad hoc working group with the view to revise the two chapters.

Against this background, the Commission would like to request the EFSA to review the scientific publications provided and possibly other sources to provide a sound scientific basis for the future.

1.1.2. Terms of Reference

The Commission therefore considers it opportune to request EFSA to give an independent view on the slaughter of animals (killing for human consumption) concerning two categories of animals:

- free moving animals (cattle, buffalo, bison, sheep, goats, camelids, deer, horses, pigs, ratites)
- 2013 animals in crates or containers (i.e. rabbits and domestic birds).

The request covers the following processes and issues:

- arrival of the animals,
- unloading,
- lairage,
- handling and moving of the animals (free moving animals only)
- restraint,
- stunning
- bleeding
- slaughter of pregnant animals (free moving animals only)
- emergency killing (reasons and conditions under which animals have to be killed outside the normal slaughter line),
- unacceptable methods, procedures or practices on welfare grounds.

For each process or issue in each category (i.e. free moving/in crates or containers), EFSA will:

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1 OJ L 303, 18.11.2009, p. 1.

2 The welfare aspects of the main systems of stunning and killing the main commercial species of animals. The EFSA Journal (2004), 45, 1–29.

3 The welfare aspects of the main systems of stunning and killing applied to commercially farmed deer, goats, rabbits, ostriches, ducks, geese and quail. The EFSA Journal (2006) 326, 1–18.

4 Electrical requirements for waterbath equipment applicable for poultry. EFSA Journal 2012;10(6):2757.

5 Electrical parameters for the stunning of lambs and kid goats. EFSA Journal 2013;11(6):3249.

6 Monitoring procedures at slaughterhouses for bovines. EFSA Journal 2013;11(12):3460.

7 Monitoring procedures at slaughterhouses for pigs. EFSA Journal 2013;11(12):3523.

8 Monitoring procedures at slaughterhouses for poultry. EFSA Journal 2013;11(12):3521.

9 Monitoring procedures at slaughterhouses for sheep and goats. EFSA Journal 2013;11(12):3522.

10 The use of carbon dioxide for stunning rabbits. EFSA Journal 2013;11(6):3250.

11 The use of low atmosphere pressure system (LAPS) for stunning poultry. EFSA Journal 2014;12(1):3488.

12 Electrical requirements for poultry waterbath stunning equipment. EFSA Journal 2014;12(7):3745.

13 The scientific assessment of studies on electrical parameters for stunning of small ruminants (ovine and caprine species). EFSA Journal 2015;13(2):4023.

14 The low atmospheric pressure system for stunning broiler chickens. EFSA Journal 2017;15(12):5056.

15 The animal welfare aspects in respect of the slaughter or killing of pregnant livestock animals (cattle, pigs, sheep, goats, horses). EFSA Journal 2017;15(5):4782.

- ToR-1: Identify the animal welfare hazards and their possible origins (facilities/equipment, staff),
- ToR-2: Define qualitative or measurable criteria to assess performance on animal welfare (animal-based measures (ABM),
- ToR-3: Provide preventive and corrective measures to address the hazards identified (through structural or managerial measures),
- ToR-4: Point out specific hazards related to species or types of animals (young, with horns, etc.).

1.2. Interpretation of the Terms of Reference (if appropriate)

The European Commission asked EFSA to provide an independent view on the slaughtering of pigs, covering all processes; for each of these, several welfare aspects needed to be analysed (including, e.g. welfare consequences, welfare hazards and preventive/corrective measures).

Slaughtering is defined as the killing of animals intended for human consumption; the related operations include handling, lairage, restraining, stunning and bleeding of animals that take place in the context and at the location where the animals are slaughtered (Council Regulation (EC) No. 1099/2009 of 24 September 2009[16]). Emergency killing is intended in this opinion as emergency slaughter.

This opinion will therefore concern the killing of pigs for human consumption, which could take place in a slaughterhouse or during on-farm slaughter, from arrival until the animal is dead. In the context of this opinion, ea ch related operation is a process, and several related operations (processes) are grouped into phases. The phases that will be assessed in this opinion are: Phase 1 – pre-stunning, Phase 2 – stunning and Phase 3 – bleeding. Phase 1 includes (in chronological order): (a) arrival, (b) unloading of animals from the truck, (c) lairage and (d) handling and moving to the stunning area. Because restraint prior to stunning varies depending on the stunning method, restraint will be assessed as a part of the relevant stunning method, including emergency slaughter situation (Phase 2). The bleeding phase (Phase 3) includes exsanguination following stunning.

Because of the diversity of available stunning methods, this opinion will consider the assessment of welfare consequences, hazards, related animal-based measures (ABMs) and mitigation measures, origin of hazards and preventive/corrective actions of the stunning methods (phase 2) including restraint.

The mandate requests EFSA to identify hazards at different stages (processes) of slaughtering and their relevant origins in terms of equipment/facilities or staff (ToR-1). When discussing the origins, it was considered necessary to explain them further by detailing what actions of the staff or features of the equipment and facilities can cause the hazard. Therefore, for each origin category (staff, facilities/equipment), relevant origin specifications have been identified by expert opinion. It has to be noted that hazards originated from the farm or during transport, which welfare consequence persist on arrival, are considered in this opinion.

It is to be noted that ToR-1 of the mandate asks to identify the origins of the hazards in terms of staff or facilities/equipment.

This Opinion will report the hazards that can occur during slaughtering of pigs in all ‘types’ of slaughterhouses (from industrial plants with automated processes to on-farm manual slaughter), but not all of the hazards apply to all slaughter situations, i.e. in small abattoirs or during on-farm slaughter. Indeed, hazards applicable to a specific stunning method may occur in all situations where this method is applied; whereas some other hazards may not apply in certain circumstances, e.g. the ones specific to the arrival or unloading of the animals in on-farm slaughter.

The level of detail to be considered for the definition of ‘hazard’ is not specified in detail. One hazard could be subdivided into multiple ones depending on the chosen level of detail. For example, the hazard ‘inappropriate electrical parameters’ for electrical stunning methods, could be further subdivided into ‘wrong choice of electrical parameters or equipment’, ‘poor or lack of calibration’, ‘voltage/current applied is too low’, ‘frequency applied is too high for the amount of current delivered’. For this opinion, it was agreed to define hazards by an agreed broad level of detail (‘inappropriate electrical parameters’ in the example above).

The mandate also asks to define measurable criteria to assess performance (i.e. consequences) on animal welfare (ABMs; ToR-2). This ToR has been addressed by identifying the negative consequences

[16] Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. OJ L 303, 18.11.2009, pp. 1–30.

on welfare (so-called welfare consequences) occurring to the pigs due to the identified hazards and the relevant ABMs that can be used to assess these welfare consequences qualitatively and/or quantitatively. In some circumstances, it might be that no ABM exist or their use is not feasible in the context of slaughtering of pigs; in these cases, emphasis to the relevant measures to prevent the hazards or to mitigate the welfare consequences will be given.

Pigs experience welfare consequences due to the presence of hazards only when they are conscious, which applies to all pigs during the pre-stunning phase. In the stunning phase, pigs may experience welfare consequences (pain and fear), if hazards occur during restraint (before stunning), if induction of unconsciousness is not immediate, or if stunning is ineffective. During bleeding following stunning, pigs will experience welfare consequences in cases of persistence of consciousness or if they recover consciousness after stunning and before death. Therefore, consciousness is not a welfare consequence per se but a prerequisite for experiencing pain and fear.

During the stunning phase, the state of consciousness is assessed to identify if animals are successfully rendered unconscious or, if they are conscious (e.g. stunning was ineffective or they recovered consciousness) and therefore at risk of experiencing pain and fear. The ABMs of state of consciousness are phrased neutrally (e.g. tonic/clonic seizures after electrical stunning). For each ABM, outcomes either suggesting unconsciousness (e.g. presence of tonic/clonic seizures) or suggesting consciousness (e.g. absence of tonic/clonic seizures) have been identified.

In this opinion, distress, which can be defined as an aversive, negative state in which coping and adaptation processes fail to return an organism to physiological and/or psychological homoeostasis (Moberg, 1987; NRC 1992; Carstens and Moberg, 2000), has not been included as a specific welfare consequence. This is due to the consideration that distress may result from e.g. pain and fear, depending on the duration and magnitude of the latter, which are among the welfare consequences addressed in this opinion, and that therefore it was not necessary to list distress separately.

In this opinion, in the description of the processes of each phase, the relevant welfare consequences that the pigs can experience when exposed to hazards will be reported. In this respect, the ranking of the identified hazards in terms of severity, magnitude or frequency of the welfare consequences that they can cause is not considered in this mandate.

The preventive and corrective measures to be provided were interpreted as those measures that can be put in place by the person responsible for the slaughtering in order to prevent or correct the identified hazards. These measures will fall into two main categories: (1) structural and (2) managerial (ToR3). Some corrective measures of the hazards will mitigate the welfare consequence (e.g. showering at lairage will correct the hazard of 'too high effective temperature' and mitigate the welfare consequence of 'heat stress'). However, other measures, although correcting the hazard, will not mitigate the welfare consequence (e.g. stop shouting will correct the hazard of 'unexpected loud noise' but will not mitigate the fear of the animals already exposed to the noise). Furthermore, train the staff not to shout will prevent the hazard. When corrective measures for the hazards are not available or feasible to put in place, actions to mitigate the welfare consequences caused by the identified hazards will be discussed. In addition, it will be assessed whether specific categories or species of domestic pigs might be subjected to specific hazards (ToR-4).

In response to an additional request from the European Commission, measures to mitigate the welfare consequences will also be described under ToR-2.

As this opinion will be used by the European Commission to address the OIE standards, it will consider more methods for slaughter than those reported in Council Regulation (EC) No 1099/2009.

Among the methods that are used for slaughter worldwide, EFSA has applied the following criteria for the selection of methods to include in this assessment: (a) all methods known to the experts that have technical specifications, i.e. not limited to the methods described in Council Regulation (EC) No 1099/2009, (b) methods currently used for slaughter of pigs and (c) methods for which the welfare aspects (in terms of welfare hazards, welfare consequences, ABMs, preventive and corrective measures) are sufficiently described in the scientific literature.

Applying these criteria in this opinion will result in the exclusion of some practices that may be applied worldwide.

The mandate also requests a list of methods, procedures or practices deemed unacceptable on welfare grounds. In order to answer to this ToR, the Panel is aware of two issues with this request. Firstly, it has to be noted that some methods, procedures or practices under question cannot be subjected to a risk assessment procedure because there is no published scientific evidence relating to them. Secondly, scientific risk assessment can only support the question of what practices are acceptable or unacceptable on welfare grounds, but ultimate decisions rather involve e.g. ethical and socio-economic considerations that need to be weighed by the risk managers.

In response to this ToR, therefore, the Panel listed practices for which welfare consequences were identified and classified as 'severe'. To do so, expert knowledge was elicited and the available scientific evidence was assessed in order to subdivide practices into two groups, namely the group of those leading to 'severe' welfare consequences and the group of those not leading to 'severe' welfare consequences. For the practices leading to severe welfare consequences, the Panel has serious welfare concerns and therefore recommends that these practices should be avoided, re-designed or replaced by other practices, leading to better welfare outcomes. These practices will be discussed in this opinion.

2. Data and methodologies

2.1. Data

2.1.1. Data from literature

Information from the papers selected as relevant from the literature search (LS) described in Section 2.2.1 and from additional literature identified by the working group (WG) experts was used for a narrative description and assessment to address ToRs 1, 2, 3 and 4 (see relevant sections in the Section 3 'Assessment').

2.1.2. Data from Member States and expert opinion

Information on the identification of hazards for pigs at slaughter existing in the EU Member States (MSs) was requested by EFSA from the AHAW Network representatives[17] (see Section 2.2.2). The data obtained from the literature and network (mainly on the hazards) were complemented by the WG experts' opinion in order to identify the welfare consequences, ABMs, hazards, hazard origins, preventive and corrective measures relevant to the current assessment.

2.2. Methodologies

To address the questions formulated by the European Commission in ToRs 1–4, three main approaches were used to develop this Opinion: (i) literature search and (ii) consultation with MSs' representatives followed by (iii) expert opinion through WG discussion. These methodologies were used to address the mandate extensively (see relevant sections in the Assessment Section) and summarised in outcome tables (see Section 2.2.3.1).

The general principle adopted in the preparation of this Opinion was that relevant reference(s) would be cited in the text when published scientific literature was available, and expert opinion would be used when no published scientific literature was available or to complete the results retrieved.

2.2.1. Literature search

A broad literature search under the framework of 'welfare of pigs at slaughter and killing' was carried out to identify peer-reviewed scientific evidence providing information on the elements requested by the ToRs, i.e. description of the processes, identification of welfare hazards, origin, preventive and corrective measures, welfare consequences and related ABMs.

Restrictions were applied in relation to the date of publication, considering only those records published after a previous EFSA Scientific Opinion on the topic (EFSA, 2004).

A total of 474 references were retrieved and reviewed by the WG members to select potentially relevant references. This screening produced 108 relevant records. Discrepancies were discussed between the WG members until a final subset of 60 relevant references was selected and considered in this assessment by reviewing the full papers.

Full details of the literature search protocol, strategies and results, including the number of the records that underpin each process, are provided in Appendix A to this opinion.

In addition, the experts in the WG selected relevant references starting from scientific papers, including review papers, books chapters, non-peer review papers known by the experts themselves or retrieved through non-systematic searches, until the information of the subject was considered

[17] https://www.efsa.europa.eu/en/animal-health-and-welfare/networks

sufficient to undertake the assessment by the WG. If needed, relevant publications before 2004 were considered.

2.2.2. Consultation of Member States' (MSs) representatives

The representatives of the EU Member States' (MSs) organisations are members of the EFSA Network on 'Animal Health and Welfare'. The dedicated Network meeting on Animal Welfare Network is held once a year to facilitate exchange of information and sharing of best practices among NCPs. At the Network meeting held in July 2019, an exercise was held, aiming at the identification of hazards for pigs at slaughter.

During this meeting, hazards for each process of slaughtering were identified and presented to the Network members. A discussion was held to agree on the terminology for the common understanding of the hazards. Finally, for each phase, network members were asked to indicate, through an online application, the hazards that were present in their countries.

The outcome of this meeting provided a list of hazards that are most common in EU MSs (EFSA AHAW Network, 2019).

2.2.3. Risk assessment methodology and structure of the opinion

The working group experts followed the risk assessment methodology from the EFSA's guidance on risk assessment in animal welfare (EFSA AHAW Panel, 2012b).

Based on expert opinion through working group discussion, the WG experts first described the phases and related processes of slaughter and specifically which stunning/killing methods should be considered in the current assessment.

Using the available literature and their own knowledge, the experts then produced a list of the possible welfare consequences characterising each process related to the slaughter of pigs. To address the ToRs, the experts then identified the hazards leading to those welfare consequences and their origin (ToR-1) and the applicable preventive and corrective measures (ToR-3). ABMs for measuring the welfare consequences were identified (ToR-2). Measures to mitigate the welfare consequences were also considered.

Related to the structure of the opinion, sections are organised by phases: phase 1 – Pre-stunning, phase 2 – stunning and phase, 3 – bleeding. Phase 1 is divided into processes (e.g. arrival, lairage). In phase 2, there is only one process, stunning, under which several methods are described (e.g. head-only electrical stunning, CO_2 at high concentration stunning). In phase 3, there is only one process: bleeding. For each process, there is a description of its welfare consequences, ABMs, hazards, preventive and corrective measures. Therefore, in each section (phases), the hazards will be listed within each stunning method.

2.2.3.1. Description of the structure of the outcome tables

The main results of the current assessment are summarised in outcome tables, which can be retrieved at the end of each specific section.

The outcome tables link all the mentioned elements requested by ToRs 1, 2 and 3 of the mandate and provide an overall outcome for each process of slaughter in which all retrieved information is presented concisely (see description of the structure below, in Table 1). Conclusions and recommendations of this scientific opinion are mainly based on the outcome tables.

The outcome tables have the following structure and terminology:

- OUTCOME TABLE: Each table represents the summarised information for each pig slaughter process (see Sections from 3.1 to 3.3).
- HAZARD: the first column in each table reports all hazards pertaining to the specific process; the number of the section where each hazard is described in detail is reported in brackets. For each hazard, the individual row represents the summarised information relevant to the elements analysed for that hazard. Therefore, it links between an identified hazard, the relevant welfare consequences, origin/s of hazards and preventive and corrective measures (see example in Table 1).
- WELFARE CONSEQUENCES OCCURRING TO THE PIGS DUE TO THE HAZARD: this column lists the welfare consequences to the pigs of the mentioned hazards.
- HAZARD ORIGIN: this column contains the information related to the category of hazard origin, which can be staff-, equipment- or facility-related. Most hazards can have more than one origin.

- HAZARD ORIGIN SPECIFICATION: this column further specifies the origin of the hazard, namely, what actions of the staff or features of the equipment and facilities can cause the hazard. This information is needed to understand and choose among the proposed preventive and corrective measures.
- PREVENTIVE MEASURE/S FOR THE HAZARD: depending on the hazard origin/s, several measures to prevent the hazard are proposed in this column. They are also elements for implementing standard operating procedures (SOP).
- CORRECTIVE MEASURE/S FOR THE HAZARDS: in this column, practical actions/measures for correction of the mentioned hazards are proposed. These actions relate to the identified origin of the hazards.
- ANIMAL-BASED MEASURES: the bottom row lists the feasible measures to be performed on the pigs to assess the welfare consequences of a hazard.

Table 1: Example of the structure of an outcome table

Hazard	Welfare consequence/s occurring to pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
(Number of section)					

ABMs: (to assess the identified welfare consequences).

2.2.4. Uncertainty analysis

The outcome tables include qualitative information on the hazards and related elements identified through the methodologies explained in Section 2.2.

When considering the outcome tables, uncertainty exists at two levels: (i) related to the completeness of the information presented in the table, namely to the number of rows within a table (i.e. hazard identification) and (ii) related to the information presented within a row of the table (i.e. completeness of hazard origins, preventive and corrective measures on the one side and welfare consequences and ABMs on the other side). However, owing to the limited time available to develop this scientific opinion, an uncertainty analysis was only performed for the first level, i.e. for the hazard identification.

Therefore, the uncertainties during hazard identification could result in two types of error:

- Misclassification (false-positive hazards): Some welfare-related hazards may be wrongly included in the list of hazards of an outcome table without being relevant.
- Incompleteness (false-negative hazards): Some welfare-related hazards may be missed in the identification process and so would be considered non-existent or not relevant.

Incompleteness (false negatives) can lead to underestimation of the hazards with the potential to cause (negative) welfare consequences.

The uncertainty analysis was limited to the quantification of the probability of false-positive or false-negative hazards.

For evaluation of the risk of occurrence of false-positive hazards in the assessment, the experts elicited for each hazard the probability that it may exist during the slaughter process and should therefore be included in the outcome table (i.e. the probability of being a true positive). For evaluation of the risk of occurrence of false-negative hazards in the assessment, the experts elicited the probability that at least one welfare-related hazard was missed in the outcome table. False-negative hazards can relate to (i) the situation under assessment, i.e. limited to the slaughter practices considered in this assessment according to the three criteria described in the Interpretation of ToRs (see Section 1.2), or (ii) the global situation, i.e. including all possible variations to the slaughter practices that are employed in the world and that might be unknown to the experts of the WG. The Panel agreed that it was relevant to distinguish the probability of occurrence of false-negative hazards under these two scenarios.

For the elicitation, the experts used the approximate probability scale (see Table 2) proposed in the EFSA uncertainty guidance (EFSA, 2019). Experts first provided individual judgements that were then discussed, and a consensus judgement was obtained. A qualitative translation of the outcome of the uncertainty assessment was also taken from Table 2.

Table 2: Approximate probability scale (see EFSA, 2019, table 4)

Probability term	Subjective probability range	Additional options	
Almost certain	99–100%	More likely than not: > 50%	Unable to give any probability: range is 0–100% Report as 'inconclusive', 'cannot conclude' or 'unknown'
Extremely likely	95–99%		
Very likely	90–95%		
Likely	66–90%		
About as likely as not	33–66%		
Unlikely	10–33%		
Very unlikely	5–10%		
Extremely unlikely	1–5%		
Almost impossible	0–1%		

3. Assessment

3.1. Phase 1: Pre-stunning

3.1.1. Introduction to pre-stunning

The pre-stunning phase includes four processes: (i) arrival, (ii) unloading from the truck, (iii) lairage, and (iv) handling and moving to the stunning area. These processes are described in Sections 3.1.2–3.1.5.

Although the processes under evaluation in this opinion start with the arrival, the period before the arrival to slaughterhouse (preparation for transport, loading and journey) also has impact on the welfare of animals at the slaughterhouse. It has been demonstrated (Faucitano, 2018) that housing conditions can influence the ease to handle and move pigs and the risk to fight when mixed with unfamiliar pigs. The author reported that animals are easier to handle and move, and fight less, when they were reared in enriched and more welfare friendly conditions compared to conventional housing. Animals reared in different groups might be mixed in waiting areas on the farm prior to loading, in the transport vehicles or at slaughter, during lairage.

Pigs will be subjected to three main stages before reaching the slaughterhouse: preparation for transport, loading on trucks and transportation. During these stages, the pigs are fasted to reduce gut content and so prevent the release and spread of bacterial contamination through faeces within the group during transport and lairage as well as through the spillage of gut contents during carcass evisceration (Faucitano and Geverink, 2008). Fasting before slaughter, within reasonable limits, is also beneficial to the welfare condition of the pig as it prevents pigs from vomiting in transit (transport sickness) and developing hyperthermia. A survey of 739 journeys to 37 slaughterhouses in five European countries revealed that the risk of mortality increased with faster movement and loading on the farm and doubled when pigs were not fasted prior to loading (Averós et al., 2008). However, when comparing long-lasting fasting (18 h) vs. not fasted animal, it appears that pigs with long fasting are more difficult to handle at loading, as they go backward, round-turn and vocalise more (Dalla Costa et al., 2016a,b). The increased frustration, fatigue and excitement caused by hunger are the likely causes for these behaviours (Faucitano, 2018). An extended fasting period causes hunger and aggressiveness (Warriss, 1994) and, if prolonged, animals become weak, lethargic and sensitive to cold (Gregory, 1998). In pigs, fat mobilisation, as the main source of energy, starts after about 16 h of starvation. After this time, Velarde recommends feeding animals with moderate amounts of food (Velarde, 2008).

In order to reach slaughter, the animals will be loaded in a truck. The stress associated with the loading procedure results from a combination of different factors, such as group splitting in the finishing pen, group size and handling system, among others (Faucitano, 2018).

After loading in the trucks, the animals are transported to the slaughterhouse. At this stage, vehicle design, control of microclimate inside and quality and length of the driving will influence welfare of animals at arrival (Arduini et al., 2017; Faucitano, 2018). The risk of mortality increases with increased average temperature (Averós et al., 2008). In a study involving five countries (739 journey in 37 slaughterhouses), Averós et al. (2008) showed that mortality increases with the length of transportation when pigs are not fasted prior to transportation compared to fasted pigs (for at least

12 h), e.g. mortality raising from 0.2% to 1% in unfasted pigs showing injuries, when the length of transportation goes from 0.5 h to 8 h. Among pigs without any recorded injury, average temperature was a more important factor influencing mortality than the duration of the journey itself (Averós et al., 2008). Schwartzkopf-Genswein et al. (2012) explained in their review that the main factors linked with transportation and affecting pig welfare are: loading density, trailer microclimate, transport duration, animal size and condition, management factors including bedding, ventilation, handling, facilities and vehicle design. They may lead to pain, fatigue, prolonged thirst, heat stress, mortality and morbidity.

It is widely accepted that the different events occurring before slaughter (e.g. during mixing and waiting in pick-up pens, loading, transport and pre-stunning) can induce acute stress and compromise welfare of pigs (Nanni Costa, 2009; Brandt et al., 2015, 2017; Faucitano, 2018). At each stage of the pre-stunning phase, pigs are exposed to different stressors inducing, psychological stress (due to changes of environment, social disturbances and handling by humans) and physical stress, due to food deprivation, climatic conditions, leading to fatigue and sometimes pain (Terlouw et al., 2016; Faucitano, 2018).

3.1.2. Arrival

Arrival of pigs at a slaughterhouse is the first process of the pre-stunning phase and it takes place from the moment the truck arrives at the slaughterhouse until the pigs are unloaded from the truck (see Figure 1).

The welfare condition of pigs at arrival represents the cumulative result of the state of animals on the farm including husbandry conditions, speed and distance of movement from their rearing sheds to the pens located at point of loading on trucks, waiting conditions in these pens, mixing of unfamiliar animals, loading methods and transport and road conditions. In commercial conditions, the waiting time to unload a truck after its arrival at the slaughterhouse is very variable ranging from 5 min to 4 h (Aalhus et al., 1992; Jones, 1999). During waiting on the truck at arrival, animals might be exposed to different environmental and microclimatic conditions due to the lack of protection of the truck (from sun, wind etc.), insufficient ventilation when the vehicle is stationary, smaller space allowance in the compartments of the truck than on farm, lack of bedding and an inappropriate type of flooring, and undergo water and feed deprivation until the pigs are unloaded. As a result, the animals can experience different welfare consequences like heat or cold stress, fatigue, restriction of movement, prolonged hunger and thirst and/or pain. If these welfare consequences are severe, persist in time or combine together, they can lead in extreme cases to the death of the animals. Delays in unloading pigs will prolong or exacerbate these welfare consequences.

The correlation between time waiting in the lorry and the risk of death and/or non-ambulatory pigs at unloading has been reported in several studies (Ritter et al., 2006; Haley et al., 2008; Faucitano and Pedernera, 2016). One study showed that if the waiting time increases by 30 min after arrival, there is a 2.2-fold increase of the risk of pigs dying (Haley et al., 2008). Faucitano and Pedernera (2016) recommend unloading the truck as soon as possible and always within 30 min after arrival at the slaughterhouse and complete it within an hour to avoid in warmer conditions heat and humidity rise inside the stationary truck and its negative welfare consequences. A good coordination (scheduling) of truck arrivals with the predicted number of pigs in lairage, lairage capacity and speed of operation as well as a number of unloading docks allowing more than one truck to unload at the same time may help to shorten waiting times in abattoirs.

According to Faucitano, the rate of animal dead on arrival (DoA) is mainly due to farming conditions rather than to transport conditions (Faucitano, 2018). The main sources of variation of DoA linked with farm condition are: housing condition, preparation of the pigs before departure from farm and loading of the pigs. In some other cases, stress links to animal handling and transport lead to shock and exhaustion in animals (e.g. porcine stress syndrome) where animal NANI (Non-Ambulatory Non-Injured; Dalla Costa et al., 2019c) or death can occur (Dalmau et al., 2016).

Figure 1: Truck of pigs waiting to be unloaded at arrival to the slaughterhouse (source: Virginie Michel, 2019)

Considering the different elements described above, it is clear that welfare of pigs may be compromised from the time of preparation for departure from the farm until the arrival at the slaughterhouse. Therefore, the assessment of welfare state of pigs at the time of arrival should be considered as a prerequisite and an important first step in fulfilling animal protection at slaughterhouse.

However, when the pigs are in the truck, it is not always possible to have access to all animals for this assessment. Only those animals in the periphery of the compartments can easily be assessed. Under these circumstances, injured or sick animals requiring urgent attention will not be identified, and therefore, the duration of the welfare consequences will be increased. What can be done is to assess the ABMs in the visible animals and extrapolate the welfare consequences to the other animals in the truck, such as signs of heat or cold stress, restriction of movement or fatigue. If heat stress occurs, animals should be unloaded as soon as possible, or measures should be taken to cool down the animals while waiting for unloading (see below). Vecerek et al. (2006) used DoA and rate of pigs dying shortly after transport as a proxy for the impact of transport conditions (e.g. distance and duration) on animal welfare. They conducted a survey from 1997 to 2004 in Czech Republic and showed that the DoA level changed depending on the transport distance – from 0.062% ± 0.007% in the case of transport distances up to 50 km to 0.335% ± 0.113% in the case of transport distances above 300 km. The increasing transport distance and higher ambient temperature in the summer months were factors that contributed to an increase of the DoA. DoA may be used as an indicator of pig welfare at arrival even if it is not possible to establish which hazards are specifically responsible for mortality, it is therefore a non-specific indicator.

Considering that:

- pigs before being transported can be sorted, mixed and deprived of food (and sometimes water) for variable duration
- pigs arriving at the slaughterhouse have been submitted to transportation under variable macro- and micro-climatic conditions, durations and conditions within the lorry pens (e.g. stocking densities)
- pigs should be unloaded from the truck as soon as possible but may remain on the truck for some time under adverse climatic conditions and eventually high stocking density before unloading
- pigs might be transported with some injuries or injured themselves during transportation

consequently, during arrival, pigs can be submitted to different elements that will impair their welfare and which are described below as welfare consequences: thermal (cold or heat) stress, restriction of movement, fatigue, pain (see Section on emergency slaughter), prolonged hunger and thirst.

3.1.2.1. Welfare consequence 'Thermal stress': assessment, hazard identification and management

Thermal stress is the inability to maintain a constant body temperature by behavioural and physiological adaptation alone. This inability can result in heat stress (Lara and Rostagno, 2013) or cold stress (EFSA AHAW Panel, 2014). In extreme or prolonged cases, welfare consequences related to thermal stress (heat stress and cold stress) can lead to multi-organ failure and death (Vecerek et al., 2006; Vitali et al., 2014).

Pigs have different strategies to influence heat production and heat loss (Aarnink et al., 2016). Heat can be lost through the following pathways: convection, conduction, radiation and evaporation (Marahrens, 2014). Heat loss through the first three mechanisms (convection, conduction and radiation) mainly depends on the temperature difference between the skin and the environment. The pig is special among mammals because it has a very limited number of sweat glands, and therefore a limited capacity to lose heat by evaporation from the skin (Yousef, 1985). Therefore, the major way pigs thermoregulate is via behavioural adaptation. The special biology of pigs means that they are vulnerable to heat stress, if the ambient temperature is high and the environment, e.g. during confinement, does not allow the required thermoregulatory behaviour to keep the animal inside the thermoneutral zone.

The effective environmental temperature (EET) is the temperature experienced (thermal environment) by an animal being a combined effect of dry air temperature, air humidity (measured as wet bulb or expressed as relative humidity), air velocity, radiative and conductive heat loss (Geers, 2007). Thermoneutral zone is defined as the range of EET that provides a sensation of comfort and minimises stress (Manteca et al., 2009). In growing and finishing pigs, the thermoneutral zone varies between dry air temperatures of 15–28°C in a humidity range between 40 and 80% (see Figure 2 from Correia-da-Silva et al., 2001). In sows, the thermoneutral zone has been reported to be 15–20°C (Yousef, 1985; Black et al., 1993; EURCAW-Pigs, 2020). These thermoneutral zones are valid on a certain level of feed intake under stable or resting conditions.

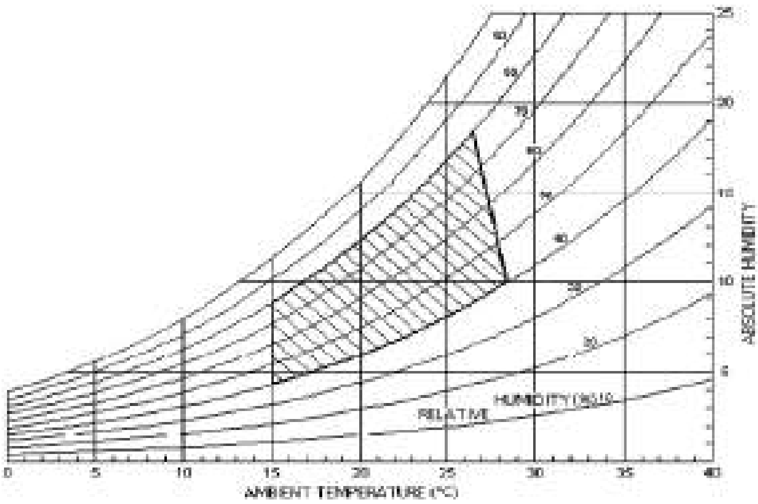

Figure 2: Thermoneutral zone for growing and finishing pigs (Correia-da-Silva et al., 2001)

Figure 3 shows the concept of thermoneutral zone. Within the temperature zone A–D, pigs can keep their body temperature constant. This thermoneutral zone can be defined as the range of environmental temperatures within which metabolic rate and heat production are minimal, constant and independent of the ambient temperature. Point A is called the lower critical temperature (LCT), while point D is called the upper critical temperature (UCT). The thermoneutral zone will vary depending e.g. on the size of the animal, its breed, plane of nutrition and environmental factors such as heat loss to the floor, air velocity around the animal, but also on motoric activity (e.g. maintaining balance during transport).

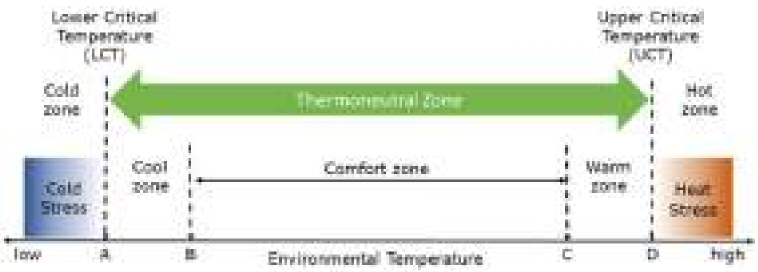

Figure 3: Schematic representation of temperature and thermal zones

In pigs, lying behaviour is an important tool within behavioural thermoregulation, and therefore related to the EET (Velarde et al., 2007). Combining measurements of pigs' energy metabolism and animal behaviour has shown that the thermal neutral or comfort behaviour for pigs occurs when they are lying on their side and touching each other. Sternal recumbency and huddling mean that it is too cold, i.e. pigs attempt to reduce heat loss. Pigs exposed to heat stress maximise conduction of body heat to the floor while minimises warming up due to contact with other pigs (Spoolder et al., 2012). So, when it is too warm, pigs lie down quickly, maintain relatively wide separation between individuals and increase their respiration rate (Santos et al., 1997).

Definition of 'Heat stress':

When the temperature is outside the upper level of this thermoneutral zone, pigs are 'heat stressed' since they show difficulty achieving a balance between body heat production and body heat loss (Dalmau and Velarde, 2016). Pigs have difficulty in dissipating heat and may suffer heat stress at ambient temperatures close to the upper limit or above their thermoneutral zone with a high humidity (Dalmau and Velarde, 2016). Heat stress increases the risk of mortality (Vecerek et al., 2006; Vitali et al., 2014).

ABMs for 'Heat stress':

In the zone from the upper threshold of the comfort zone (C) to the UCT (see Figure 3) as a limit of the thermoneutral zone (D), evaporative heat loss increases considerably. At higher environmental temperatures beyond the UCT, pigs show increased respiration rates (panting). In addition to experiencing increased heat loss, the pigs increase the exposure of their bodies to cool air or cool and wet surfaces to increase conductive heat loss (behavioural thermoregulation) (EURCAW-Pigs, 2020)

Panting and discolouration of the skin (for definition see Table 3) are specific indicators of heath stress of pigs after transportation, when arriving in the slaughter premises. Dead on arrival (DoA) is not a specific indicator of pig heat stress but in case of very hot conditions, combined with other factors like lack of ventilation, fatigue, etc. DoA can be recorded as ABM. At arrival, the difficulty is to be able to see properly all the animals. In case it is possible, the percentage of animals panting and presenting discolouration of the skin can be recorded as specific ABM. When the vehicle is stationary, animals in the middle of the lorry might have less ventilation and higher effective temperature than animals in the periphery of the compartments. Therefore, these animals, that are more difficult to be assessed due to the position in the middle of the lorry, might experience more severe heat stress.

Assessment of 'Heat stress' at arrival can be done by counting the proportion of animals showing the ABMs reported in the following table (Table 3).

Table 3: ABMs for assessment of 'Heat stress' at arrival

ABM	Description
Discolouration of the skin	Changes from light to redder colour of the skin (Pilcher et al., 2011)
Panting	Breathing with short, quick breaths with an open mouth (Dalmau et al., 2009c; Welfare Quality®, 2009)

Hazards leading to 'Heat stress':

1) Too high effective temperature.
2) Insufficient space allowance in the lorry.

Too high effective temperature:

In hot and humid environmental conditions, poor ventilation will exacerbate heat stress. When the lorry is stationary at arrival, effective temperature will increase due to the lack of ventilation. A too high effective temperature is characterised by the fact that the thermoregulatory capacities of the pigs to maintain homoeothermy are challenged (see Figure 3). They show difficulty achieving a balance between body heat production and body heat loss that leads to heat stress. Heat stress also increases water requirements and can therefore increase the risk of prolonged thirst if water supply is not provided in the lorry.

Within a vehicle in transit, the internal temperature can increase by almost 1°C at each 1°C increase in the environmental temperature (Dewey et al., 2009). The internal temperature increases more, up to 3–4°C in 5 min at a rate of approx. 1°C/min, in passively ventilated vehicle held in a stationary situation (Lambooij, 1988; Xiong et al., 2015). The variation in the internal thermal might depend on the side openings influencing the air flow inside the vehicle (Weschenfelder et al., 2012) as well as the rate of ventilation, which can be mechanical.

The origins of this hazard are mainly linked to high environmental temperature and humidity, lack of a skilled operator (to manage properly the situation), absence of ventilation, high density with impossibility to lie in lateral recumbency for thermoregulation on the truck and/or prolonged waiting time before unloading.

Insufficient space allowance in the lorry: In this context, space allowance refers to the amount of space pigs have available in the lorry for thermoregulation and is expressed in area (in m^2) per animal. Physical space requirements increase with increasing body weight ('BW') and thermoregulation needs in case of heat stress. The relationship between the three factors is described through the formula $A = k*BW^{2/3}$ (Petherick, 1983) where 'A' is the floor area covered by the pigs and 'k' is a constant value that depends on the posture for thermoregulation. Recently, Bracke et al. (2020) reviewed the requirements for space during transport. They report that for sternal lying k = 0.019, which is a much lower k-value than for lateral lying (k = 0.046), where the pig is lying 'square' on its side with the legs stretched out and without touching another pig. For pigs that have a slaughter weight of 110 kg, k = 0.019 equates to 0.44 m^2 and k = 0.046 equates to 1.06 m^2.

Bracke et al. (2020) suggest that 'at high ambient temperatures, when the animals need to lose heat, k-values between 0.033 and 0.047 are advisable. This will allow the animals to lie laterally'. Therefore, at upper critical temperatures, insufficient space for all pigs to lay down in lateral recumbency will prevent them the possibility for thermoregulation and might exacerbate heat stress.

Prevention and correction of 'Heat stress' and its related hazard

Immediate assessment of the animals at arrival would certainly enable the responsible person to decide upon appropriate corrective actions for alleviating further negative welfare consequences or immediate stunning and slaughter of animals as an ultimate intervention.

When ambient temperature is above 23°C, it was shown that water sprinkling of pigs for 5 min in the truck before leaving the farm and during waiting time in the lorry at arrival in the slaughterhouse reduced heat stress as seen by a reduction of drinking behaviour in lairage, physical fatigue at slaughter (lower blood lactate levels) and water loss in meat (Fox et al., 2014). Pereira et al. (2018) compared identical trailers positioned along a fan-misting bank with others with no access to this cooling system in the same slaughterhouse in Brazil. Although the efficiency of the fan-misting bank varied by compartment location in the lorry, this cooling system appeared to be effective in improving the thermal comfort of the pigs kept in the stationary trailer.

However, water sprinkling combined with insufficient ventilation can also result in increased difference in humidity levels (up to + 7.5%) between the trailer interior and the external environment (Fox et al., 2014), preventing efficient evaporative cooling in pigs.

A crucial preventive measure to consider for (planning) transport is to avoid transport during the hottest hours of the day in order to avoid extreme temperature, especially when trucks are not equipped with forced ventilation systems. To prevent and correct high effective temperatures experienced by the pigs in hot climatic conditions, pigs should also be protected from direct exposure to the sunlight and unloaded immediately from the truck. At arrival, it is suggested to provide shelter and adequate ventilation in order to get close to the recommended conditions of 15–28°C and 59–65% humidity (Dalmau and Velarde, 2016).

Definition of 'Cold stress':

When the temperature is below the lower limit of the thermoneutral zone (below LCT, see Figure 3), pigs are 'cold stressed' since they show difficulty achieving a balance between body heat production and body heat loss (Dalmau and Velarde, 2016), and their capacity of maintaining their body temperature is challenged.

ABMs for 'Cold stress':

When pigs are subjected to cold stress at arrival, they may show shivering and/or huddling behaviour in the lorry pens, and, in extreme conditions, dead animals can be seen, but this ABM is not specific of cold stress (except in extreme situations which are rare). At arrival, observing properly all animals can be challenging. In case it is possible, the proportion of animals shivering and huddling can be taken as a specific ABM.

Assessment of 'Cold stress' at arrival can be done by assessing the percentage of animals showing the ABMs reported in the following table (Table 4).

Table 4: ABMs for assessment of 'Cold stress' at arrival

ABM	Description
Huddling	When a pig is lying with more than half of its body in contact with another pig(i.e. virtually lying on top of another pig). It is not considered huddling when an individual is just side by side and alongside another animal. (Dalmau et al., 2009c; Welfare Quality®, 2009)
Shivering	Shaking slightly and uncontrollably (Strawford et al., 2011)

Hazards leading to 'Cold stress':

Too low effective temperature:

In cold and humid environmental conditions with high wind speed, the effective temperature will decrease rapidly. During winter season, a higher proportion of DoAs and non-ambulatory pigs on arrival at the slaughterhouse has been reported (Guàrdia et al., 1996; Sutherland et al., 2009), with higher risk of death at a temperature range between 4 and 10°C compared to a range between 12 and 26°C (Peterson et al., 2017).

The origins of this hazard are described in the Outcome table, in Section 3.1.2.6; they are mainly linked to cold climatic conditions, lack of skilled operator (not able to deliver suitable protection to animals), absence of protection from wind and environmental temperatures on the truck and/or prolonged waiting time before unloading.

Operating sprinklers, when the ambient temperature is 5°C or below, are detrimental to the welfare of pigs (Knowles et al., 1998). Therefore, sprinklers should not be used at this ambient temperature.

Prevention and correction of 'Cold stress' and its related hazard

Some preventive measures can be taken at the time of transportation, e.g. when the temperature is below the lower level limit of the thermoneutral zone avoiding the coldest hours of the day for transportation. Cold stress in the truck can be controlled by partially closing the ventilation openings (boarding) in order to reduce air flow and by adding a minimum of 5 cm layer of Styrofoam to the vehicle top ceiling (Gonyou and Brown, 2012) and bedding on the truck floor (TQA, 2016).

If effective temperature is still below the thermoneutral zone (this can be checked by measuring huddling and shivering animals), pigs should be unloaded immediately. In case this is not possible, adequate shelter should be provided to allow pigs protection from the wind. Heating systems can be provided in the waiting area, if needed. These measures (unloading as soon as possible, protection from wind and heating) can be used separately or in combination, depending on how critical the situation is. They can act as preventive or corrective measures for the hazard and as well to mitigate the welfare consequence.

3.1.2.2. Welfare consequence 'Prolonged thirst': assessment, hazard identification and management

Definition of 'Prolonged thirst':

The animal has been unable to get enough water to satisfy its needs, resulting in dehydration.

ABMs for 'Prolonged thirst':

There is no specific ABM feasible at arrival process.

Hazard leading to 'Prolonged thirst':

1) Too long water deprivation

Too long water deprivation

Water deprivation time is the period that starts when the water is removed on farm in order to load the animals for transport to slaughterhouse and ends when pigs have access to water again (in the lorry pen or in lairage pens).

This can result in prolonged dehydration that can lead to difficulties in coping with high temperatures (cumulative effect of hazards). Water deprivation time is the result of the time elapsed between the water deprivation on farm and the loading of animals plus the transportation time (when no water is available in the lorry pens) and waiting time before unloading on arrival, until they have access to water in the lairage pens. This hazard's origin is mainly due to staff lack of knowledge about pig care, leading to pigs left too long without access to water (on farm, during transport and/or at slaughterhouse).

Prevention and correction of 'Prolonged thirst' and its related hazards

To prevent this hazard and its direct welfare consequence, 'prolonged thirst', pigs need to have access to water on farm until being loaded on the truck and ideally while in the truck as well. At arrival, the only recommendable corrective measure is to unload pigs as soon as possible in order to provide them with water immediately in lairage or slaughter them as soon as possible. This can be achieved by careful planning of these processes (including the transport time), and by scheduling and prioritising the slaughter of the animals.

3.1.2.3. Welfare consequence 'Prolonged hunger': assessment, hazard identification and management

Definition of 'Prolonged hunger':

Deprivation of food leading to a craving or urgent need for food or a specific nutrient, accompanied by an uneasy sensation and eventually leading to a weakened condition (Merriam-Webster dictionary[18]), as metabolic requirements are not met.

ABMs for 'Prolonged hunger':

There is no specific ABM to assess prolonged hunger at arrival. In an established group, some aggressive behaviours occurring can be interpreted as signs of prolonged hunger. However, in mixed groups, unfamiliarity can lead to aggression as well and therefore this indicator cannot be used in this case.

Hazards leading to 'Prolonged hunger':

Too long food deprivation:

Food deprivation time is the period that starts when the feed is removed on farm in order to load the animals for transport to slaughterhouse.

According to Warriss et al. (Warriss and Brown, 1994; Warriss et al., 1998), fasting must be longer than 4 h before transportation in order to reduce motion sickness and mortality. Brown et al. (1999) showed that the incidence of severe skin damage, indicating aggressive encounters, increased when fasting lasted more than 12 and 18 h compared to 1 h. In pigs, fat mobilisation, as the main source of energy, starts after about 16 h starvation. The total food deprivation time before slaughtering should not exceed 16 h (Dalla Costa et al., 2016a). After this time, animals should be fed with moderate amounts of food.

Although the time of pre-slaughter feed withdrawal should be limited, there is a risk of feed being removed too early at the farm, transport being delayed or prolonged and/or too long waiting time before unloading and/or too long lairage period resulting in too long food deprivation.

[18] https://www.merriam-webster.com/dictionary/hunger

Prevention and correction of 'Prolonged hunger' and its related hazard

To prevent 'too long food deprivation', the feed withdrawal should be planned, taking into account the waiting at farm, transport and lairage periods. It is recommended that the time elapsed between on-farm withdrawal and end of lairage does not exceed 18 h (Dalmau and Velarde, 2016). This can be achieved by careful planning of these processes (including the transport time), and by scheduling and prioritising the slaughter of the animals. The only identified corrective measure is to unload and slaughter animals immediately.

3.1.2.4. Welfare consequence 'Fatigue': assessment, hazard identification and management

Definition of 'Fatigue'

Physiological state representing extreme tiredness and exhaustion of an animal.

ABMs for 'Fatigue':

Animals presenting fatigue at arrival are often laying or sitting and are often unable to walk since they are too exhausted. These animals are often non-ambulatory, non-injured (NANI) pigs unable to move by themselves even if they do not show any specific injury. The ABMs that can be used for this welfare consequence are: exhaustion, muscle tremor and dyspnoea (Benjamin, 2005). Animals are fatigued when they exhibit several of these ABMs at the same time. When it is possible to see the animals, the percentage of animals showing these ABMs (Dalla Costa et al., 2019a) can be recorded.

Assessment of 'Fatigue' at arrival can be done by counting the number of animals showing the three ABM in Table 5.

Table 5: ABMs for assessment of 'Fatigue' at arrival

ABM	Description
Exhaustion	Animals lying on the floor and not able to stand up: recumbency (Benjamin, 2005)
Muscle tremor	Uncontrolled movement of leg muscle (Benjamin, 2005)
Dyspnea	Excessive rate of open mouth breathing (Benjamin, 2005)

Hazards leading to 'Fatigue':

1) too high effective temperature, (for details see Section 3.1.2.1)
2) too long water deprivation (for details see Section 3.1.2.2)
3) too long food deprivation (for details see Section 3.1.2.3)
4) insufficient space allowance in the lorry.

The physiologic challenges induced by 'too high effective temperature', independently or cumulated with 'food and/or water deprivation too long' will lead to exhaustion of body reserve and fatigue.

<u>Insufficient space allowance in the lorry:</u>

In relation to fatigue, space allowance is the amount of space an animal has available for physically occupation and for behavioural activity. If space allowance is reduced too much, pigs cannot rest properly, resulting in fatigue.

As discussed above, the physical space required by pigs of different weights can be calculated through the formula $A = k*BW^{2/3}$ (Petherick, 1983). From this, it can be calculated that for 110 kg pigs which are standing or lying on all four legs (k = 0.019), the required space is 0.44 m^2. However, for movement and interactions of pigs in the lorry, additional space is needed. This will also allow resting pigs to lie down undisturbed. This is confirmed by Lambooij et al. (1985), who suggest that at 235 kg/m^2 (so k = 0.0197) not all pigs are able to lie down and rest at the same time due to the frequent disturbance of lying animals by those seeking a place to rest (Lambooij and Engel, 1991). Furthermore, Pilcher et al. (2011) showed that increasing the floor space from 0.40–0.49 m^2/100 kg (k = 0.0186–0.0227) to 0.52 m^2 (0.0241) helps reducing the incidence of fatigued pigs on arrival at the slaughterhouse after journeys shorter than 1 h. Finally, in a study by Gerritzen et al. (2013), it was shown that with a loading density of 179 kg/m^2 (k = 0.0259), pigs displayed more resting behaviour compared with the loading density of 235 kg/m^2 (k = 0.0197).

Fitzgerald et al. (2009) reported that reducing the space allowance from 212.4 to 338.6 kg/m^2 (so from k = 0.022 to k = 0.014) corresponds to a 7.5-fold increase in Dead on Arrivals (DOAs) at the slaughterhouse. Similarly, Ritter et al. (2012) found that losses of pigs due to transport are lower when 0.46 m^2 per 100 kg pig is provided (k = 0.021) compared to 0.39 m^2 (k = 0.018) (Ritter et al., 2012).

Visser et al. suggest after a review of the literature that when animals are transported at ambient temperatures in their comfort zone, without the need to access food or water, a 'k-value' of 0.0192 appears to be enough. This equates to 0.439 m^2 for a 110 kg live weight pig. When animals need room for resting, feeding and obtaining water, Visser et al. (2014) consider that a k-value of 0.0274 is more appropriate. This equates to 0.629 m^2 for a 110 kg live weight pig.

Prevention and correction of 'Fatigue' and its related hazards:

The prevention and correction measures regarding the hazards too high effective temperature and too long water and food deprivation are described in Section 3.1.2.1 to 3.1.2.3. Fatigue is often originating from conditions prior to arrival at slaughter. Good conditions at loading on farm (such as ramp slope < 20°), and reduction of transport and loading times can be way to prevent pig fatigue at arrival (Dalla Costa et al., 2019c).

Regarding space allowance, according to Dalmau and Velarde, 2016, stocking densities, which are directly linked to the space allowance, should be adjusted according to:

- the temperature/humidity combination in the truck
- waiting time in the lorry at arrival
- if animals are familiar or not
- distance and speed of the journey

Regarding these elements, the only preventive measure for insufficient space allowance is to adjust the number of pigs to the size of the pen in the truck. The minimum space allowance should be 0.439 m^2 for a 110 kg live weight during resting, while this is 0.629 m^2 for a 110 kg live weight when animals need room for resting, feeding and obtaining water (Visser et al., 2014). Considering if animals are familiar or not (allow more space for subordinate to escape in case of unfamiliar animals) and the climatic conditions (allow more space in warm conditions) are also important factors. No corrective measures for the hazard insufficient space allowance exist, except to unload pigs as soon as possible.

Pigs presenting fatigue at arrival should be segregated during unloading if they are able to stand up and walk unassisted and inspected by a veterinarian and/or trained professional. To the pigs unable to walk unassisted, a procedure for emergency slaughter should be applied in situ, as soon as possible, to prevent further suffering (Faucitano and Pedernera, 2016). The provision of some pens next to the unloading area that can be used as hospital pens will facilitate the recovery of animals arriving exhausted or with any problems other than those that require emergency slaughter on the lorry or in the unloading bay (Dalmau and Velarde, 2016).

3.1.2.5. Welfare consequence 'Restriction of movement': assessment, hazard identification and management

Definition of 'Restriction of movement':

The animals are unable to move (e.g. to avoid aggression or seek resources such as lying space, feed or water) as a result of insufficient space available.

***ABMs for 'Restriction of movement'*:**

At arrival, it is very difficult to see animals in the lorry pens to unequivocally assess restriction of movement. Therefore, assessment of space allowance can be considered as a proxy. Space allowance is the amount of space an animal has available for physically occupation and for behavioural activity and is usually expressed in area (in m^2) per animal. It can be calculated by dividing the area available to a group (in m^2) of pigs by the group size.

Hazards leading to 'Restriction of movement':

Insufficient space allowance for moving (for details see Section 3.1.2.4)

Prevention and correction of 'Restriction of movement' and its related hazards:

The space allowance should be adjusted according to body weight, environmental conditions and travel time. As a preventive measure, it is recommended to adjust the number of pigs to the size of the compartment when loading at the farm (for details see prevention related to space allowance in Section 3.1.2.4).

As it is not feasible to provide more space for the pigs in the truck pens at arrival, the mitigation measures should be to unload the pigs as soon as possible and then to offer sufficient space allowance for all pigs to be able to lie at the same time in lairage, or to slaughter them as soon as possible.

3.1.2.6. Outcome table on 'Arrival'

Table 6: Outcome table on 'Arrival'

Hazard	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Too high effective temperature (see Section 3.1.2.1)	Heat stress, fatigue	Equipment, facilities, staff	Lack of skilled operators High environmental temperature and humidity Not enough ventilation in the truck Prolonged waiting time Insufficient space allowance to lie in lateral recumbency	• Staff training • Increase space allowance • Scheduling to avoid hottest hours of the day for transport • Unload immediately following the arrival • Provide adequate ventilation to the truck at arrival place • Protect from adverse weather conditions	Provide adequate ventilation or/and cooling systems
Too low effective temperature (see Section 3.1.2.1)	Cold stress	Equipment, facilities, staff	Lack of skilled operators Low environmental temperature No protection from the environment (e.g. close the openers in the truck) Prolonged waiting time	• Staff training • Prepare the vehicle according to weather conditions (including providing bedding material • Avoid coldest hours of the day for transport • Unload immediately following the arrival • Provide adequate shelter to the truck at arrival place	Provide protection when the pigs are on the truck Unload the truck immediately and bring the pigs to a thermo neutral zone (with heaters)
Insufficient space allowance (see Sections 3.1.2.4; 3.1.2.5)	Restriction of movements, fatigue heat stress	Staff	Lack of skilled operators Too many animals put in the truck compartments	• Staff training • Adjust the number of pigs to size of the compartment	Unload the animals immediately
Too long food deprivation (see Section 3.1.2.3)	Prolonged hunger, fatigue	Staff	Lack of skilled operators Pigs removed too early from their housing pens Prolonged transport and/or prolonged waiting time	• Staff training • Planning of feed withdrawal on farm according to duration of transportation and waiting time prior to slaughter • Scheduling slaughter of animals • Prioritising slaughter	Provide food and water to the pigs Slaughter immediately

Hazard	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Too long water deprivation (see Section 3.1.2.2)	Prolonged thirst, fatigue	Staff	Lack of skilled operators Pigs removed too early from their housing pens Prolonged transport and/or prolonged waiting time	• Staff training • Pigs should have access to water till loading on the truck	Provide water to the pigs Slaughter immediately

ABMs: panting, discolouration of the skin (heat stress), shivering, huddling (cold stress), exhaustion, dyspnoea, muscle tremor (fatigue), no feasible ABMs for prolonged hunger and thirst.

3.1.3. Unloading from the truck

Following arrival at the slaughterhouse, pigs should be unloaded from the truck as soon as possible and moved to lairage or slaughter area. In practice, the most common unloading device at the slaughterhouse is the ramp or bridge, which helps the transfer of pigs from the truck ramp or lift to the dock (Faucitano and Geverink, 2008; Velarde and Dalmau, 2012; Faucitano and Pedernera, 2016).

To avoid overlapping, slipping, falling, jamming, vocalisation and turning back on the ramp during unloading, pigs should be unloaded by compartment on each deck rather than by deck, and in small groups using only paddles and/or boards to move them (Rabaste et al., 2007; Faucitano and Geverink, 2008). In properly designed and constructed facilities, with competent animal handlers, it should be possible to move almost all animals without any falling.

Under commercial conditions, common tools for moving pigs at unloading are plastic paddles and boards, electric goads and flags. These tools do not have the same efficiency and the same effects on pig behaviour and physiology during handling (Faucitano and Goumon, 2017). The electric prod seems to be used on farm and on the truck to speed up the procedure of loading and reduce the workload of handlers through the alleys and ramps (Griot and Chevillon, 1997; Faucitano, 2001; Correa, 2011). However, electric goads or other painful stimuli are a source of severe pain, reduce the ease of handling (McGlone et al., 2004) due to increased backing-up, round turns, slipping, falling and jamming (Rabaste et al., 2007; Correa et al., 2010; Edwards et al., 2010a; Dokmanovic et al., 2014) and produce a negative physiological response in terms of higher and greater heart rates and blood lactate concentrations (Correa et al., 2010; Edwards et al., 2010a). The frequent use of electrical goads may also result in a higher incidence of fatigued pigs at unloading (Correa et al., 2013). Ritter et al. (2008) showed that stimulating pig with an electric prod more than twice and for more than 1 s per hit during handling causes a negative physiological response, in terms of increased rectal temperature and blood lactate concentration. In a search for alternative handling tools, McGlone et al. (2004) compared the efficiency and effects of flags, paddles and plastic boards and concluded that the plastic board and the flag were the most efficient devices for moving pigs because they appear as solid, blocking walls. Correa et al. (2010) concluded that to improve animal welfare (i.e. lower exsanguination blood lactate), the electric prod should be replaced with paddles or compressed air goads. Therefore, during unloading and moving from lairage to stunning point, recommended tools will be flags, paddle and plastic boards.

Pigs that are fatigued (Section 3.1.2.4) or severely injured during transport might be only identified at the time of unloading (Figure 4). The handling and movement of these animals, that might be unable to walk, will exacerbate their fatigue and pain. Furthermore, the manipulation of the animals to be introduced in a trolley and moved to the slaughter will also be painful. In these cases, the unloading of these animals by any means should be avoided and emergency slaughter (Section 3.4) should be applied as soon as possible to prevent further suffering.

Figure 4: Using a board for unloading pigs (Source: Virginie Michel)

The unloading area covers the ramp of the truck, the unloading bay and the raceway until lairage. When the slaughterhouse does not have a ramp, the unloading area extends from the beginning of the truck ramp.

3.1.3.1. Welfare consequence 'Impeded movement': assessment, hazard identification and management

Definitions of 'Impeded movement':

Difficulty to physically move (i.e. walk) resulting in slipping and falling.

ABMs for 'Impeded movement':

Impeded movement can be measured by counting animals slipping or falling (referred to as 'Ease of movement' in Welfare Quality®, 2009).

Assessment of 'impeded movement' during handling and moving can be done by counting animals showing the ABMs reported in the following Table 7 and calculating the percentage of animals affected.

Table 7: ABMs for assessment of 'Impeded movement' at unloading

ABM	Description
Falling	Loss of balance, in which part(s) of the body (beside legs) are in touch with the floor (Dalmau et al., 2009c; Welfare Quality®, 2009).
Slipping	Loss of balance, without (a part of) the body being in touch with the floor (Dalmau et al., 2009c; Welfare Quality®, 2009).

Hazards leading to 'Impeded movement'

The impairment of animal welfare at this stage can be mainly due to two hazards:

1) Improper design, construction and maintenance of premises
2) Rough handling.

<u>Improper design, construction and maintenance of premises</u>

According to Dalmau et al. (2009a,b), impeded movement can be attributed to characteristics of the facilities, especially angle and slope of unloading ramps.

This hazard occurs when the unloading area is not well designed (angle, depth of slope, flooring, lack of foot battens or lateral protection etc.) so that it causes impeded movement to animals. This implies that pigs will slip and fall and have increased reluctance to move, which may increase rough handling, leading to additional fear and/or injuries of pigs during unloading.

Faucitano and Pedernera (2016) explained that, when compared to ramps, the use of hydraulic lifts or decks reduces handling stress, increases the easiness of handling and shortens off-load time. A greater heart rate, balking behaviour and unloading time have been reported in pigs dealing with angles or bends of 45° to 90° compared with 0° and 30° (Warriss et al., 1991; Goumon et al., 2013). Keeping in mind that pigs have difficulties in descending a slope (Brown et al., 2005), ramps steeper than 20° are not recommended as they result in greater increases in pigs' heart rate, vocalisation and backing up behaviour, increased intervention by the handler (eventually shouting and use of electric goads) and increase the time required for unloading by a factor of 3–4 (Warriss et al., 1991; Ritter et al., 2008; Goumon et al., 2013; Torrey et al., 2013a,b; Faucitano and Pedernera, 2016). To ease handling, pigs should not have closed corners to deal either when exiting the truck or on the unloading ramp (Faucitano and Pedernera, 2016). Current guidelines do not recommend ramps steeper than 20° to be used for fixed ramps (Warriss et al., 1991) or than 25° for adjustable ramps. However, as market pigs have become heavier and difficult to move (Bertol et al., 2005, 2011; Rocha et al., 2016), recent works recommend the maximum ramp slope to be reduced to 15° (Grandin, 2012; Faucitano and Goumon, 2018).

Rough handling

Rough handling is defined as handling where people are using the wrong material (e.g. goads instead of flags and boards) or forcing the pigs to get off from the truck too quickly or through non-adapted bridges and raceways. In pigs, rough handling, electric goads use or jamming in the single file raceway resulted in higher blood lactate levels and poorer meat quality (Edwards et al., 2010a,b; Dokmanovic et al., 2014; Grandin, 2016).

Prevention and correction of 'Impeded movement' and its related hazard

Pigs have difficulties in descending a slope (Brown et al., 2005). Therefore, it is recommended as a preventive measure to avoid ramps steeper than 20° and for heavy slaughter pigs, even reduce it to 15°. Other preventive methods include: cover the gaps (e.g. between the vehicle and the ramp), avoid steps (> 15 cm) and slippery floors, use hydraulic lift or dock instead of ramps and avoid the design of raceways with close corners (Faucitano and Pedernera, 2016). Foot battens, rubber mats and deep groove flooring can help animals to avoid slipping and falling. No corrective measure is available in case of poor design and maintenance of premises.

When design of unloading area is not adequate, using adapted handling methods for unloading pigs with a low speed of moving can help reducing impeded movement.

In any case, to prevent rough handling, staff has to be trained to learn how to behave with pigs; they should act calmly and gently, without shouting and using the right tools e.g. flags, boards and panels instead of electric goads. In case of rough handling, corrective actions can be to stop the staff from shouting, rushing or using the wrong tools and have them behave correctly.

3.1.3.2. Welfare consequence 'Pain and Fear': assessment, hazard identification and management

Definitions of 'Pain' and 'Fear':

Pain: Unpleasant sensory and emotional experience associated with actual or potential tissue damage (IASP, 1979).

Fear: Emotional state induced by the perception of a danger or a potential danger that threatens the integrity of the animal (Boissy, 1995).

Unloading pigs from the truck in the unfamiliar environment of the slaughterhouse by unfamiliar people is always stressful for animals. Fear will be the more common welfare consequence induced by either personnel (i.e. rough handling) or/and improper design and maintenance of the premises or/and by sudden noise occurring outside the truck.

Pigs might be severely injured during transport and suffer from severe pain at arrival. Unloading and moving of these severely injured pigs or those unable to move independently without pain, will lead to additional pain and fear and will increase risk of pain due to slips and falls (Dalmau et al., 2009c).

ABMs for 'Pain' and 'Fear':

Fear can be measured by high pitched vocalisations, escape attempts, reluctance to move and animals turning back, especially when they are scared by people. Dalmau et al. (2016) studied 10,616 pigs in 42 different abattoirs in five countries and showed a mean percentage of 4.36% [range: 0–37.5%] and 4.95% [range 0–21%] pigs showing reluctance to move and turning back, respectively, during unloading. According to Dalmau et al., 2009a,b, reluctance to move can be attributed to the characteristics of the facilities, especially angle and slope of unloading ramps (see 'impeded movement' Section), and turning back is more associated with handling, usually in the context of driving large groups of pigs.

Slipping and falling described above can lead to injuries, leading to pain. Animals can also suffer from injuries originating from the rearing period, loading and/or transport. When an animal is injured in a foot or a limb, the injury leads to pain that may be expressed as lameness. In the slaughterhouse context, lameness can always be considered related to pain due to an injury, an infection or/and inflammation. Pain, especially when acute, can lead to high pitched vocalisations in pigs.

The animal welfare, as affected by pain and/or fear, can be assessed during unloading by counting the proportion of animals with injuries or lameness and the occurrence of high pitched vocalisations, reluctance to move, animals turning back and escape attempts described in the following Table 8 (Dalmau et al., 2009c, 2016; Welfare Quality, 2009; O'Malley et al., 2018).

Table 8: ABMs for assessment of 'Pain' and 'Fear' at unloading

ABM	Description	Welfare consequence
Escape attempt	Attempts to move or run away from the situation (O'Malley et al., 2018)	Pain, fear
High pitched vocalisation	Squealing or screaming, when pigs are moved or manipulated (adapted from Welfare Quality®, 2009).	Pain, fear
Injuries	Tissue damage (bruises, scratches, broken bones, dislocations) (EFSA AHAW Panel, 2012a)	Pain
Lameness	Inability to use one or more limbs in a normal manner. It can vary in severity from reduced ability or inability to bear weight to total recumbency (Dalmau et al., 2009c; Welfare Quality®, 2009).	Pain
Reluctance to move	An animal that stops for at least 2 s not moving the body and the head (freezing) or that refuses to move when coerced by the operator (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c).	Fear
Turning back or turning around	When an animal facing towards the unloading zone (e.g. the ramp or the lift) turns around and attempts to return to the vehicle (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c)	Fear

Hazards leading to 'Pain' and 'Fear':

The impairment of animal welfare at this stage can be mainly due to three hazards appearing either alone or most of the time combined:

1) Improper design, construction and maintenance of premises (see section 3.1.3.1)
2) Rough handling (see Section 3.1.3.1)
3) Unexpected loud noise

Improper design, construction and maintenance of premises

This hazard occurs when the unloading area is not well designed as described in the Section 3.1.3.1 so that it causes pain and fear to animals, in particular due to the presence of shadows, changes in flooring, moving objects, loud noises or poor quality lighting arrangements and other forms of distractions such as hose pipes in the raceway or protecting clothing hanging on the walls (Grandin, 2016).

Handling problems due to hesitation and refusal of pigs to go forward since they are scared, can also be caused by for example poor lighting, lack of shelter at the dock, the presence of a step (> 15 cm) or a gap between the truck deck floor and the unloading dock and a slippery ramp floor.

Rough handling

Rough handling was defined as handling where staff is using the wrong material (e.g. goads instead of flags and boards) or forcing the pigs to get off from the truck too quickly or through not adapted bridges and raceways. Then, moving manually pigs in an inappropriate way will cause pain and/or fear to the pigs resulting in balking, refusing to move, turning around or backing up in the raceway. When animals are acting this way, employees are more likely to use force and harsh methods such as multiple shocks with electric goads to move them (Grandin, 2016).

Unexpected loud noise

This is a noise that by its level suddenly induces fear to the animals.

A slaughterhouse is an environment in which loud noises originating mainly from machines, gates clanging and sometimes from pigs and personnel shouting may occur, even if they should be avoided. Iulietto et al. (2018) studied a way to monitor the level of noise in pig slaughterhouses (n = 3) with a smartphone app. For the pig lines, the average values expressed in dB ranged from 77.50 (SD 3.11) to 100.33 (SD 1.53) for abattoir 1, from 83.00 (SD 2.00) to 99.75 (SD 2.63) for abattoir 2 and from 71.20 (SD 6.49) to 99.50 (SD 1.31) for abattoir 3. The highest values (i.e. 100 dB) were always measured at the slaughter hall compared to the unloading area (i.e. 79 dB). Vocalisations of stressed animals and human shouting, which is particularly abhorrent for animals (Weeks, 2008), are stressful for animals. As an example, Spensley found that novel noise ranging from 80 to 89 dB increased heart rate of pigs (Spensley et al., 1995). Other authors showed that intermittent sounds are more disturbing to pigs than continuous sound (Talling et al., 1996, 1998). They found an increased heart rate and ambulation score in piglets after exposure to different sounds greater than 85 dB, suggesting that sound can activate the pigs' defense mechanisms. Therefore, it can be concluded that sounds higher than 80–85 dB are deleterious to pig welfare since they induce increase in heart rate, interpreted as fear.

Prevention and correction of 'Pain' and 'Fear' and their related hazards

It is recommended that non-ambulatory, injured or those pigs unable to move independently without pain or to walk unassisted should be stun '*in situ*' (see 3.4 Emergency slaughter) appropriately, and the carcass moved to the slaughter area. Such pigs should never be dragged, lifted or handled in a trolley as it will exacerbate pain. The emergency slaughter should be done before attempting to unload other animals in order to prevent trampling and further compromises in welfare such as pain and fear of non-ambulatory animals and/or blocking the pathway preventing other animals from being unloaded. This situation is not marginal since Dalmau showed that on 245 lorries unloaded, 81% contained at least one sick animal and 91% at least one dead (Dalmau et al., 2016). Therefore, attention must be paid before unloading for the inspection of animals and the correct handling of the non-ambulatory ones.

Design, construction and maintenance of the premises should promote the voluntary and natural displacements of the animals and minimise the potential for distractions. This should also apply to the ambient condition such as light, avoid shadows etc.

Personnel should be calm and patient, assisting the animals to move using a soft voice and slow movements. They should not shout, kick or use any other means that are likely to cause fear or pain to the animals. Under no circumstances should animal handlers resort to violent acts to move animals applying moving aids to sensitive parts of the animals (rectum, eyes, nose etc.). In order to move pigs, staff is recommended to use the flight zone and point of balance principle; use flags, paddles or pig boards instead of electric goads; move the pigs in small groups using their natural 'following' behaviour (Grandin, 2016).

It is important to limit unexpected and intermittent loud noises because they lead to fear and decrease coping capacities. The preventive measures will consist in staff education and training (i) to make them aware that noise should be avoided and (ii) to make them avoid shouting and making noise with the equipment and facilities and identify and eliminate the sources of noise. Regarding facilities and equipment, machines should be setup correctly to avoid excessive noise and facilities should be noise proofed (e.g. foam-core insulation board instead of precast concrete). As corrective measure staff must stop shouting and handle pigs correctly.

Staff training has been identified as a common preventive measure to avoid all hazards identified at unloading.

3.1.3.3. Outcome table on 'Unloading of pigs from the truck'

Table 9: Outcome table on 'Unloading of pigs from the truck'

Hazard	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Rough handling (see Sections 3.1.3.1; 3.1.3.2)	Pain, fear, impeded movement	Staff	Lack of skilled operatorsImproper handling of animals; use of electric goadsImproper equipment	• Training of staff for proper handling; appropriate equipment to move animals.	Staff stop rough handling and start handling correctly pigs
Improper design, construction and maintenance of premises (see Sections 3.1.3.1; 3.1.3.2)	Pain, fear, impeded movement	Facilities	Improper slope, lighting, slippery floor, absence of solid lateral protection, presence of a gap between the lorry and the ramp	• Ensure maintenance of the area. • Rebuild the unloading area regarding recommendation and animal behaviour	Ensure good lightening, avoid of shadows and remove distractions
Unexpected loud noise (see Section 3.1.3.1)	Fear	Staff	Staff shouting and making noise	• Identify and eliminate the source of noise, staff training, avoid personal shouting	Staff stopping shouting

ABMs: Injuries, lameness (pain), high pitched vocalisations (pain, fear), escape attempt, reluctance to move and turning back (fear), slipping and falling (impeded movement).

3.1.4. Lairage

The lairage is the period between the entry of the animals into the lairage area (after being unloaded off the truck) until they are taken out from the pen to move to the stunning point. During lairage pigs are normally kept in pens (see Figure 5), covered areas or fields associated with or being part of slaughterhouse operations. One of the purposes of the lairage is to maintain an adequate reserve of animals to ensure continuous provision of pigs on the slaughter line (Dalmau and Velarde, 2016). Another purpose of lairage is to provide stressed or fatigued animals an opportunity to recover from the stress of transport and previous handling in order to produce better meat quality (Faucitano, 2010, 2018). Dall Aaslyng and Barton-Gade (2001) concluded that there is no need of lairage if pre-slaughter handling is inducing only low stress or in populations without the halothane gene. Prolonged periods of lairage can decrease pig welfare (Dalla Costa et al., 2019b). Nevertheless, to allow pigs to rest after transport, the lairage should allow the animal to satisfy comfort around resting (Welfare Quality®, 2009) and thermal comfort as well as by providing enough space for the animal to be able to move around freely and to move away in case of aggressive behaviours. To satisfy its need of comfort around resting, each animal shall have enough space to stand up, lie down and turn around. Minimal lying area requirements can be calculated based on body weight. Where lairage pen space is limited, it is important to schedule truck arrivals carefully. Otherwise, animals would have to wait in the truck, compromising their welfare.

Several requirements must be considered for an appropriate lairage, such as space allowance, floor and wall conditions (including bedding), provision to water, provision of food when necessary, presence of shower and fans to cool down animals under hot conditions, light, noise and lairage time (Dall Aaslyng and Barton-Gade, 2001).

Figure 5: Lairage pens with water provision (Source: Virginie Michel 2019)

Pig groups are usually mixed on farm prior to loading in order to obtain groups of uniform weight and to adjust the group size to that of the truck compartments (Velarde, 2008). The disruption of groups often leads to aggression at lairage to establish a new dominance hierarchy (Terlouw et al., 2008; Terlouw and Gibson, 2016). The interactions generally start within minutes after mixing and the incidence and level of fighting often depends on the presence of a few aggressive animals in the group (Geverink et al., 1996) and are generally increased at lower space allowance (Geverink et al., 1996), in larger compared to smaller groups (Schmolke et al., 2004) and in pigs that have been food deprived

(Brown et al., 1999). The fighting rate and subsequent skin lesion scores increase with lairage time (Warriss et al., 1996 and Faucitano, 2001, 2010). Guàrdia et al. (2009) reported an almost twofold higher risk of skin lesions in pigs kept in lairage for 15 h compared to 3 h (18% vs. 10%). The increased level of aggression over time can be explained by the effect of fasting on pigs' frustration and nervousness, with animal deprived of food for up to 18 h fighting more than animals deprived from food for up to one hour (Brown et al., 1999).

Lairage is the place where the health and welfare of the pigs can be assessed and therefore should have adequate lighting to allow inspection of the animals.

The welfare consequences for lairage are presented below.

3.1.4.1. Welfare consequences 'Negative social behaviour': assessment, hazard identification and management

Definitions of 'Negative social behaviour':

Negative social behaviour is defined as any behavior associated with features involving aggression or mounting (Welfare Quality).

Conflicts with pen mates as well the inability for subordinate animals to escape the dominant ones can lead to fear. In case of negative social behaviour, animals can be injured and suffer from pain. Continuous fights can lead to resting problems and fatigue.

ABMs for 'Negative social behaviour':

Negative social behaviour can be assessed by the occurrence of aggressive behaviour, including fighting, biting as well as mounting behaviour. Aggression can be measured by injuries and in extremes cases death (Dalmau and Velarde, 2016). ABMs and their definitions are reported in Table 10.

Table 10: ABMs for assessment of 'Negative social behaviour' at lairage

ABM	Description
Aggressive behaviour	Negative social interactions such as fighting, head-knocking, threatening and biting (Welfare Quality®, 2009)
Mounting	An animal placing one or two forelimbs on another animal's loin at any point

Hazards leading to 'Negative social behaviour'

1) Mixing unfamiliar animals

Mixing unfamiliar animals

This is the main hazard for the occurrence of negative social behaviour.

Mixing unfamiliar animals is to place together animals that were not pen-mates during the rearing or fattening period. They can be placed together while waiting to be loaded in the truck at the farm, during transportation and/or in the lairage pens. Unfamiliar animals are likely to fight to establish new social ranks (Fàbrega et al., 2013, cited by Dalmau and Velarde, 2016) or due to competition for limited resources like place for resting or water. These negative social interactions might cause also fear, pain and fatigue.

Prevention and correction of 'Negative social behaviour' and its related hazards

Lairage can be often the source of stress since animals will be placed in a novel environment and in contact with unfamiliar people or mixed with unfamiliar animals. Barton-Gade (2008) showed that welfare of mixed pigs at lairage decreases compared to that of unmixed animals. This is mainly due to higher occurrence of fighting. Outdoor reared pigs were less aggressive than conventionally reared ones. To reduce negative welfare consequences, the mixed groups of animals should be slaughtered without undue delay after their arrival at the slaughterhouse (Dalmau and Velarde, 2016).

To prevent negative social behaviour, pain, fear and fatigue due to fighting as consequence of mixing unfamiliar animals, it is recommended to keep animals in familiar groups. In case it is unavoidable to mix animals and as fighting occurs mainly during the first hours after mixing, it is recommended to mix pigs just prior to loading or on the transport pen rather than in the slaughterhouse and to maintain the same transport groups during lairage (different lairage pen size should be available). This seems to facilitate familiarisation and recognition of new animals, helping to reduce the intensity and duration of aggressions in lairage, which have detrimental effect on welfare (Dalmau and Velarde, 2016). Some European slaughterhouses managed to reduce fighting by enriching the pen with corn kernels scattered on the floor, which may distract pigs, or sprinkling the back of pigs with vinegar that apparently masks the individual smell of each pig (Eyes on Animals, 2019). Visual contact between groups of unfamiliar animals should be avoided, e.g. providing solid walls. In order to reduce fighting in lairage, pigs should be kept in (i) small groups: less bites and head knocks in small groups of 10 pigs than in groups of 30 pigs (Rabaste et al., 2007); or (ii) very large groups: Grandin, 2000 showed that there was less fighting when mixing occurred in a large group of 200 pigs than mixing smaller groups of 6–40 animals (Dalmau and Velarde, 2016).

3.1.4.2. Welfare consequences 'Pain' and 'Fear': assessment, hazard identification and management

Definitions of 'Pain and fear'

For definitions of 'pain' and 'fear', see Section 3.1.3.2.

ABMs for 'Pain and fear'

Assessment of 'Pain and fear' in lairage can be done by counting the number of high-pitched vocalisations and the number of injuries on the animals (see Table 11).

Table 11: ABMs for assessment of 'Pain and fear' at lairage

ABM	Description	Welfare consequence
Injuries (pain)	Tissue damage (EFSA AHAW Panel, 2012a)	Pain
High pitched vocalisation (fear)	Squealing or screaming, at group level when pigs are moved from lairage to the stunning area (Dalmau et al., 2009c; Welfare Quality®, 2009)	Pain, fear

Hazards leading to 'Pain and fear'

The impairment of animal welfare at this stage can be mainly due to the hazards listed below, appearing alone but most of the time combined:

1) Improper design, construction and maintenance of premises
2) Unexpected loud noise
3) Mixing of unfamiliar animals (see Section 3.1.4.1).

Improper design, construction and maintenance of premises:

During lairage, features related to the pen design or poor maintenance of the pen may result in injuries and pain (e.g. broken gates and metal parts). Exposure to hard or abrasive surfaces during resting will also provoke injury or lameness.

Unexpected loud noise:

Pigs can be exposed to noise in all the processes of slaughtering, but it is of main impact during the pre-stunning phase and, in particular, during lairage, because pigs remain here for a longer period of time.

Pig lairage areas are particularly noisy (Weeks et al., 2009), with average noise levels ranging from 76 to 108 dB and the highest peaks reaching 120 dB (Talling et al., 1996; Rabaste et al., 2007). Pigs appear to be more stressed by industrial sounds than by sounds of conspecifics (Geverink et al., 1998). Excessive lairage noise induces a fear response in pigs, as showed by the number of pigs huddling in the pen looking for protection or escaping from the source of sound (Geverink et al., 1998), the increased heart rate, and greater blood lactate, CK and cortisol levels at slaughter (Faucitano, 2010).

Prevention and correction of 'Pain', 'Fear' and their related hazards

As preventive measures, keeping the sound level lower than 85 dB in the lairage area appears to reduce the risk for PSE meat (Vermeulen et al., 2015). To reduce the ambient sound level, some European slaughterhouses replaced metal gates and fencing with plastic ones and modified the ceiling by decreasing the height and installing sound-absorbing materials (Eyes on Animals, 2019). Such measures can be performed as preventive methods.

To prevent pain, fear and fatigue due to fighting as a consequence of mixing unfamiliar animals, it is recommended to keep animals in familiar groups (see previous section).

Lairage areas should be free from sharp edges and other hazards that may cause injury to animals. Floor, wall and gate conditions must be adequate, easy to clean and repair, and with smooth and rounded surfaces to avoid injuries to the animals (Grandin, 1990). Solid floor with an adequate slope for water/urine evacuation is preferred to slatted floor, especially if animals are not familiar with this type of floor. The drinkers should be designed and constructed to allow all animals easy access without being injured.

3.1.4.3. Welfare consequence 'Thermal stress': assessment, hazard identification and management

Definition of 'Thermal stress':

In the lairage area, temperature variation can be significant and depend on the time of the day, the season and the equipment of the lairage zone.

For definition of heat and cold stress, see Section 3.1.2.1.

ABMs for 'Thermal stress':

At lairage, the percentage of animals showing panting as well as discolouration of the skin can be used to monitor heat stress (see Section 3.1.2.1). In extreme uncontrolled conditions, dead animals can be seen in case of heat stress. The percentage of the animals shivering and huddling can be used to monitor cold stress in pigs. Pigs are less sensitive to cold than to heat. Therefore, death of animals can occur in very extreme cases but cannot be used as a routine indicator of cold stress.

Assessment of 'Thermal stress' at lairage can be done by counting the proportion of animals showing the ABMs reported in the following Table 12.

Table 12: ABMs for assessment of 'Thermal stress' at lairage

ABMs	Description	Welfare consequence
Panting	Short, quick breaths with an open mouth (Welfare Quality®, 2009)	Heat stress
Discolouration of the skin	Changes from light to redder colour of the skin (Pilcher et al., 2011)	Heat stress
Shivering	Shaking slightly and uncontrollably (Strawford et al., 2011)	Cold stress
Huddling	When a pig is lying with more than half of its body in contact with another pig (i.e. virtually lying on top of another pig). It is not considered huddling when an individual is just side by side and alongside another animal. (Welfare Quality®, 2009)	Cold stress

Hazards leading to 'Thermal stress'

1) Too high effective temperature (for definition, see Section 3.1.2.1)
2) Too low effective temperature (for definition, see Section 3.1.2.1).
3) Insufficient space allowance (for definition, see Section 3.1.2.1)

Vitali et al. (2014) collected data from 2003 to 2007 of pigs (160 kg, n_{pigs} = 3,676,153, $n_{transports}$ = 24.098) transported to three slaughterhouses. Results showed that pigs had a higher risk of dying during summer (June to August) compared to the risk in other months winter (January, March, September and November) when considering both transport and lairage ($P < 0.05$).

Prevention and correction of 'Thermal stress' and its related hazards

The lairage should provide pigs with protection against adverse weather conditions, including shade. If the effective temperature is still above the thermoneutral zone (it can be checked by measuring temperature and relevant AMBs), ventilation should be provided and, in certain cases, showering, misting or nebulisation can be applied to cool down the pigs (with cold water between 10–12°C, Dalmau and Velarde, 2016). These authors proposed an intermittent showering of no more than 10–30 min at arrival in lairage and just before moving the pigs to stunning. This in order to have the greatest cooling effect and reduce aggression. To optimise the cooling effect, it is recommended that the spray is able to penetrate the hair and wet the skin. Therefore, misting is not really recommended since it might increase humidity without penetrating the hair. However, in order to remove the excessive humidity produced by the application of sprinkling/misting systems as well as to control the concentration of noxious gases, e.g. ammonia (Weeks, 2008), this practice must be combined with a proper ventilation (Brent, 1986; Weeks, 2008). Showering is not recommended when the ambient temperature is below 5°C, as it causes shivering in pigs (Knowles et al., 1998).

These measures (ventilation, showering) can be used separately or in combination, depending on how critical the situation is. They can act as preventive measures, but if not applied first, can act as corrective measures for the hazard and to mitigate the welfare consequence.

When temperature is too low at lairage, then adequate shelter should be provided to allow pigs protection from the wind. Heating systems can be provided if needed. It is recommended that bedding is provided for young animals or for long lairage.

Measures such as protection from wind, provision of bedding and/or heating can be used separately or in combination, depending on how critical the situation is. They can act as preventive or corrective measures for the hazard and to mitigate the welfare consequence cold stress (see Section 3.1.2.1).

3.1.4.4. Welfare consequences 'Prolonged thirst and hunger': assessment, hazard identification and management

Definition of 'Prolonged thirst and hunger':

For definition of prolonged thirst and hunger, see Sections 3.1.2.2 and 3.1.2.3.

It has to be noticed that prolonged hunger and/or thirst can bring the animal to its physiologic limits and induce fatigue due to exhaustion of animal's reserves and adaptation capacities.

ABMs for 'Prolonged thirst and hunger':

As in previous processes, there is no feasible ABM to detect prolonged hunger, since the duration of hunger is often not long enough to impair body condition. Prolonged thirst is normally not observed in lairage, since it is possible and then recommended to supply animals with water. Regarding food, as explained previously for food safety reason, animals cannot be fed, unless re-fasted again before proceeding to slaughter. If, for any reason, animals are thirsty, aggression due to competition for access to water troughs will be considered as an ABM to detect prolonged thirst.

Assessment of 'Prolonged thirst' at lairage can be done by counting the proportion of animals showing the ABMs reported in the following Table 13.

Table 13: ABMs for assessment of 'Prolonged thirst' at lairage

ABM	Description
Increased aggressions at water trough	Aggressive encounters at the water through

Hazards leading to 'Prolonged thirst and hunger'

1) Too long food deprivation: (see Section 3.1.2.3)
2) Too long water deprivation

Food deprivation described under the 'arrival' section will be prolonged by the period of lairage since usually no food is provided in lairage.

<u>Too long water deprivation</u>

During transport, animals are usually deprived of water, what might provoke dehydration and prolonged thirst. In the lairage, thirst is usually corrected by allowing the animals to drink. Lack of water provision as well as an inappropriate design or construction of the drinking point that prevent pigs to have easy access to clean water at all times will exacerbate dehydration.

Prevention and correction of 'Prolonged hunger and thirst' and their related hazards

To prevent prolonged hunger, the planned food withdrawal should take into account waiting at farm, transport and lairage times. It is recommended that the maximum time between on-farm withdrawal and end of lairage does not exceed 18 h (Dalmau and Velarde, 2016). This can be achieved by careful planning of these processes (including the transport time), and by scheduling and prioritising the slaughter of the animals. The only identified corrective measure is providing food to the animals during lairage. In this case, provision of water is important to minimise prolonged hunger because, physiologically speaking, pigs need to have water available if they are to continue eating.

To prevent or correct prolonged thirst from transport, clean water should always be available in the lairage pen. The supply system should be designed and constructed to allow all animals easy access to clean water at all times, without being injured or limited in their movements, and so that the risk of the water becoming contaminated with faeces is minimised (Velarde, 2008). The number and location of the water supply points should minimise competition. It is recommended by Dalmau and Velarde, 2016 that clean water is always available and reachable by every animal, with a maximum of 10 pigs/drinker (Welfare Quality®, 2009; Panella-Riera et al., 2012; Dalmau et al., 2016). Special attention should be paid to suckling piglets since they might not know how to drink with the devices used in lairage. In this case, appropriate source of water should be provided. The only identified corrective measure is providing water to the pigs.

3.1.4.5. Welfare consequences 'Fatigue': assessment, hazard identification and management

Definitions of 'Fatigue':

For definition see Section 3.1.2.4. Other welfare consequences such as restriction of movement and resting problem can lead to fatigue.

ABMs for 'Fatigue':

Animals experiencing fatigue will show immobility, recumbency and exhaustion (for description, see Section 3.1.2.4).

Assessment of 'Fatigue' in lairage can be done by counting the proportion of animals showing the ABMs reported in the following Table 14.

Table 14: ABMs for assessment of 'Fatigue' at lairage

ABMs	Description
Exhaustion	Animals lying on the floor and not able to stand up and respond to stimulus (Benjamin, 2005)
Muscle tremor	Uncontrolled movement of leg muscle (Benjamin, 2005)
Dyspnoea	Excessive rate of open mouth breathing (Benjamin, 2005)

Hazards leading to 'Fatigue'

Fatigue can be due to the following hazards:

1) Too high effective temperature (see Section 3.1.2.1)
2) Too long water deprivation (see Section 3.1.2.2)
3) Too long food deprivation (see Section 3.1.2.3).
4) Insufficient space allowance (See Section 3.1.2.5)
5) Mixing unfamiliar animals (see Section 3.1.4.1)

In lairage, water should be available to animals so that they can rehydrate if needed. Combination of water deprivation and high effective temperature can increase the phenomenon of fatigue. Delayed slaughter will increase the effect of these five hazards and can then seriously impair welfare.

Prevention and correction of Fatigue and its related hazards

To prevent fatigue, depending on its main causes, the following measures can be taken:

- allow animals to rest in good conditions in lairage (space, comfort and avoid unfamiliar animals)
- allow animals to recover from heat stress or avoid subjecting them to heat stress
- provide water in lairage to avoid suffering from prolonged thirst or to rehydrate animals
- provide food if pig reserves are too low for its energy requirement.

As a corrective measure, when pigs are suffering from fatigue in lairage, they should be given good conditions to recover and be slaughtered as soon as possible. If they cannot move, emergency slaughter should be performed.

3.1.4.6. Welfare consequences 'Restriction of movement' and 'Resting problems': assessment, hazard identification and management

Definitions of 'Restriction of movement' and 'Resting problems'

For definition of restriction of movement, see Section 3.1.2.5.

Resting problems: the animal is unable to rest comfortably because of insufficient space or space of inadequate quality in terms of surface texture, dryness and hygiene.

ABMs for 'Restriction of movement' and 'Resting problems'

As described before (for details, see Section 3.1.2.5), in lairage, like in transport, pigs should have space to lie without being in contact with other animals. There is no specific feasible ABM at lairage, but space allowance can be considered as a proxy to assess if animals have enough space to rest, access water and run away from aggressors.

There is no ABM for resting problems.

Hazards leading to 'Restriction of movement' and 'Resting problems'

Hazards responsible for these two welfare consequences are:

1) Insufficient space allowance
2) Improper design construction and maintenance of premises.

Insufficient space allowance

In an Italian study comparing three slaughterhouses for heavy pigs (160 kg), Vitali et al., 2014 showed that the risk ratio of 'dead in pens at lairage' was lower at the slaughterhouse with the lowest stocking density (0.64 m^2/100 kg live weight). Sufficient space in lairage is important, and it is recommended that each animal has enough space to stand up, lie down and turn around. The space allowance (A in m^2) required to do this is directly linked to the body weight (BW in kg) of the pig, and dependent on a k-value that is related to pig posture, via the equation $A = k*BW^{2/3}$ (Petherick, 1983).

As described in a previous section (see Section 3.1.2.1), the k-value needed for standing is k = 0.019. This equates to 0.436 m^2 for a 110 kg pig. This space is insufficient for moving in a group. EFSA (2005) discusses the way in which the necessary additional space can be calculated and estimates it to be k = 0.036 at temperatures around the pigs of up to 21°C.

Ekkel et al. (2003) reported that at thermoneutral conditions, pigs take up to 80% of space allowance for lying and 20% for activity and the latter includes dunging area, which equates to a total k-value of 0.036. This translates into 0.82 m^2 for a 110 kg pig, and 0.69 m^2 for a pig of 85 kg. When the temperature increases (above 25°C), all the animals will tend to rest in lateral recumbency and the space allowance should be 1.10 m^2/100 kg live weight, which equates to a k-value of 0.047 (Velarde and Dalmau, 2018).

Improper design, construction and maintenance of premises

That means that the design and/or maintenance of the lairage area are not fulfilling pigs' needs to comfortably recover before slaughter, inducing resting problems, restriction of movement and resting problems. The design and the maintenance of the lairage area cannot be considered adequate unless it fulfils the following requirements:

- Provide enough space to allow thermal comfort, comfort at resting, access to drinkers and possibility for the subordinate pigs to avoid aggression.
- Protect animals from adverse conditions and ensure 15–18°C and 59–65% humidity in order to allow comfort at resting time (Honkavaara, 1989 cited by Dalmau and Velarde, 2016).
- Stimulate resting of the animals (by providing walls).
- Have pens of different sizes in order to adapt to different flock sizes without mixing unfamiliar animals.
- Avoid visual contact between groups of unfamiliar animals (e.g. provide solid walls).
- Provide solid floor, smooth, non-slippery and easy to clean with adequate slope for water and urine evacuation.
- Provide bedding for piglets in cold weather condition and for all animals staying more than 12 h in lairage area.
- Provide lighting so that animals can move easily.

Prevention and correction 'Restriction of movement', 'Resting problems' and their related hazards

In order to prevent restriction of movement and resting problems in lairage, the following measures can be taken:

- Provide a minimum of 0.82 m^2 per finishing pig of 110 kg at thermoneutral temperatures, and more if temperatures should be higher or pigs larger.
- Providing appropriate design and maintenance of the pens, by including hard walls to rest around and dry and smooth flooring.

Corrective measures are valid only when inappropriate maintenance occurs: cleaning, providing bedding, draining the floor. Regarding inappropriate design of lairage area, no corrective measure is available, except to provide to animal adequate surface (remove animals from an overstocked pen) and the furnishing they need or proceed to slaughter as soon as possible in case their welfare is severely impaired.

3.1.4.7. Outcome table on 'Lairage'

Table 15: Outcome table on 'Lairage'

Hazard	Welfare consequence/s occurring to the rabbits due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Mixing unfamiliar animals (see Sections 3.1.4.1; 3.1.4.2; 3.1.4.4)	Pain, fear, negative social behaviour, fatigue	Staff and facilities	Mixing animals from different origins	• Keep familiar animals together from farm to slaughter • Increase space allowance, provide protections and provide enrichment • Showering	Remove aggressive animals, Slaughter mixed groups immediately
Unexpected loud noise (see Section 3.1.4.2)	Fear	Equipment, facilities, staff	Staff shouting, machine noise, poor design and construction of the facilities	• Identify and eliminate the source of noise; staff training; avoid personnel shouting; proper machine construction; avoid noisy equipment close to the pigs	Remove the source of noise, stop shouting
Insufficient space allowance (see Sections 3.1.4.3; 3.1.4.4)	Restriction of movements, resting problem, heat stress,	Staff	Too many animals are put in the pen	• Staff training • Adjust the number of pigs to the size of the pen • Display notice regarding number of maximum animals in each pen, regarding the category	Prioritise slaughtering of pigs with insufficient space allowance
Improper design, construction and maintenance of premises (see Section 3.1.4.3)	Pain, Restriction of movement, resting problem,	Staff, facilities	Inappropriate conception at the building of the facilities, no or insufficient cleaning of the area/evacuation of water	• Design and maintenance of the facilities regarding pig behaviour requirements and avoiding injuries	Clean and dry the lairage area, repair broken features, provide bedding
Too high effective temperature (see Section 3.1.4.5)	Heat stress, fatigue	Equipment, facilities, staff	High environmental temperature and humidity, not enough ventilation in lairage, prolonged lairage time	• Staff training • Increase space available • Scheduling transports to avoid waiting period at lairage during hottest hours of the day • Reduce the lairage time Provide adequate ventilation and cooling system (e.g. showering,) in lairage	Slaughter pigs immediately Provide cooling system (shower) to bring the pig to the thermoneutral zone

Hazard	Welfare consequence/s occurring to the rabbits due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Too low effective temperature (see Section 3.1.4.5)	Cold stress	Equipment, facilities, staff	No protection of the lairage area against wind and rain. No heating system	• Staff training • Provide curtains and other protection and close the ventilation • Avoid waiting period in lairage during coldest hours of the day at lairage • Reduce the lairage time. • Do not shower continuously when environmental temperature is below 5°C • Protect lairage area from adverse climatic conditions, provide adequate bedding	Slaughter immediately
Too long food deprivation (see Section 3.1.4.6)	Prolonged hunger, fatigue	Staff	Feeders removed too early on farm prolonged transport and/or prolonged waiting time Prolonged lairage time	• Staff training • Planning of feed withdrawal on farm according to duration of transportation and waiting time prior to slaughter • Scheduling slaughter of animals • Prioritising slaughter. • Providing food when a delay is expected in the slaughter process	Slaughter immediately
Too long water deprivation (see Section 3.1.4.6)	Prolonged thirst, fatigue	Staff	Waiting area (in farm) without drinkers Prolonger transport Absence of effective watering in lairage	• Staff training • Water availability until loading of farm • Provide access to water in the lairage and check the functioning of the watering system.	Slaughter immediately

ABMs: injuries (pain), high pitched vocalisations (fear), aggressive behaviour and mounting (negative social behaviour), exhaustion, dyspnoea, muscle tremor (fatigue), panting, discolouration of the skin (heat stress), shivering, huddling (cold stress), no feasible ABMs for prolonged hunger, increased aggressions at water trough (prolonged thirst).

3.1.5. Handling and moving of the animals to the stunning point

Handling and moving refer to the process of driving pigs to the stunning point.

Pre-slaughter handling facilities should be carefully designed and constructed. In addition, the environment should be controlled to keep the level of pain and fear to the minimum. High throughput rates require well-designed and constructed handling and restraining facilities to achieve good welfare standards in abattoirs. Personnel involved in handling and moving of animals should be properly trained and understand and use species-specific behavioural principles to ensure and maintain these standards (Grandin, 1991, 1996; www.grandin.com/index.html).

Grandin illustrates the flight zone where people should not stand (Grandin, 2016) and if pigs are reluctant to move, handlers should use the point of balance to have the animals moving forward in a single line raceway by being behind this point, on the tail side of the body (Dalmau et al., 2009b; Figure 6; Figure 7). When moving the pigs from the lairage area, the same principle applies: the handler has to stay behind the pigs to move them forward. As being separated from pen mates is a stressful situation for pigs, it is recommended to move animals in groups or in line, one following the other (Figure 8).

The movement of pigs from the lairage to the stunning point can be facilitated by adequate lighting of these areas. Pigs are less reluctant to move from a dark area to a brightly lighted area (Van Putten and Elshof, 1978; Grandin, 1990; Tanida et al., 1996) making the use of moving tools less necessary. Grandin (2010) observed that the insufficient light (less than 160-215 lux) at the entrance of the stunning area increased the use of electric goads by 34%. The alleys must be consistently lighted to avoid shadows and contrasts in colour on the floor. Recently, it has been observed that the use of green lighting lowers the shadows on the floor and improve ease of handling through the alleys (Eyes on Animals, 2019).

Movement of pigs is easier when carried out in small groups, according to design of facilities available. Dalla Costa et al., 2019a studied the effect of different group sizes of pigs (3, 5 and 10 pigs) during handling 360 pigs. The difficulty of handling and moving of pigs increase as the group size increased. Ideally operators should be able to reach all the animals in the group, if required to facilitate easy of movement.

Figure 6: Moving pigs from the lairage area with a specific board (Source: Virginie Michel).

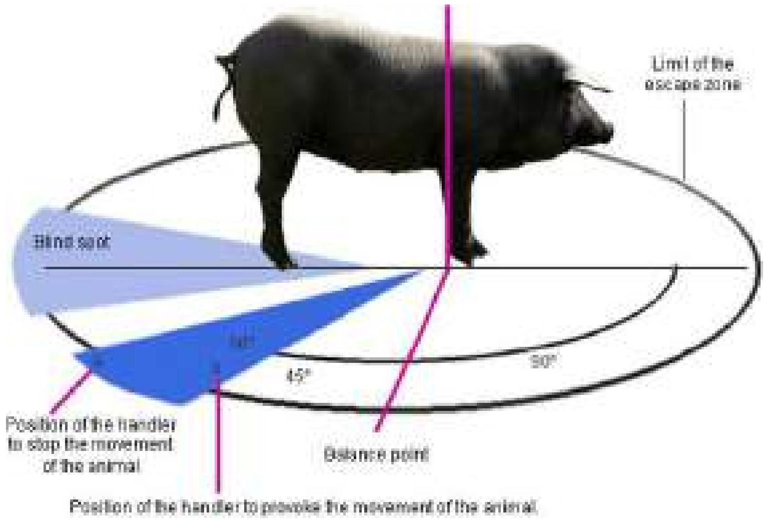

Figure 7: Example of positions to be adopted by the staff to move the pigs easily (Dalmau et al., 2009b)

Figure 8: Handling of pigs in lines in order to reach an electrical stunner (Source: Virginie Michel)

3.1.5.1. Welfare consequences 'Impeded movement': assessment, hazard identification and management

Definition of 'Impeded movement': see Section 3.1.3.1.

Impeded movement is a difficulty of movement of the pigs resulting in slipping and falling when moving from lairage to the stunning area. It will provoke fear and pain. This will happen if the handling is not appropriate or the raceway not well designed and maintained; then animals might experience impeded movement, not going smoothly into the raceway, slipping, falling and eventually hurting themselves. If pigs have been injured previously, for example, during transport or during a fight in lairage, or are suffering from lameness, impeded movement can be worsened.

ABMs of 'Impeded movement':

The movement from the lairage pen to the stunning area constitutes one of the key points regarding animal welfare in abattoirs. Therefore, welfare of pigs should be carefully assessed at this stage (Velarde and Dalmau, 2012). In abattoirs with high slaughter throughput, most of the time animals are forced to move quickly during the last metres prior to stunning to maintain the chain speed. During moving and handling of animals, some studies report the use of a 'handling scoring' for welfare assessment. These scoring contained the measurement of percentages of animals slipping or falling, use of electric goads, occurrence of high-pitched vocalisation, immobilisation, back-up, turning back (Grandin, 1997, 2001, 2017; Welfare Quality®, 2009; Rocha et al., 2016).

ABMs that are suggested in this opinion for the assessment of 'Impeded movement' are the same as those used in the unloading (Section 3.1.3.1) process i.e. slipping and falling and are reported in the following table (Table 16). The assessment is done by counting the percentage of animals showing the ABMs reported.

Table 16: ABMs for assessment of 'Impeded movement' during handling and moving of the animals

ABM	Description	Welfare consequence
Slipping	Loss of balance, without (a part of) the body touching the floor (Dalmau et al., 2009c; Welfare Quality®, 2009)	Impeded movement
Falling	Loss of balance in which any part(s) of the body (except the legs) touch the floor (Dalmau et al., 2009c; Welfare Quality®, 2009)	Impeded movement

Hazards leading to consequences 'Impeded movement':

Difficulties in handling and moving the animals are mainly linked to handling mistakes by the personnel (rough handling) and/or flaws in the design, construction and maintenance or construction of the raceways to stunning point. As an example, yelling has been demonstrated as highly stressful for animals (Grandin, 2016).

The hazards are:

1) Improper design, construction and Maintenance of premises
2) Rough handling (see Section 3.1.3.1).

Improper design, construction and maintenance of premises:

When the animals are moving from the lairage area to the stunning point, they generally are expected to go through a raceway in a single line. If the raceway is not well designed (angle of the slope, type of floor, etc.) or maintained (slippery, etc.), this could lead to impeded of movement due to slipping or falling (see more details in Section 3.1.3.1).

Rough handling

The combination of fast slaughter speed, poorly designed handling systems and large groups during the short period between the exit from the lairage pen and stunning may result in a greater proportion of slips, jamming, backing-up and vocalisation (Warriss et al., 1994; Edwards et al., 2010a, 2011; Van de Perre et al., 2010; Vermeulen et al., 2015; Rocha et al., 2016), and an increased use of electric goads (Rocha et al., 2016). These behavioural responses have been associated with a greater heart rate (Correa et al., 2010, 2013), exsanguination blood lactate and CK concentrations (Hambrecht et al., 2005a,b; Edwards et al., 2010a; Rocha et al., 2015), and higher skin lesions scores (Rabaste et al., 2007; Faucitano and Goumon, 2018) likely linked with poor welfare.

Prevention and correction of 'impeded of movement' and its related hazards

To prevent impeded movement, Grandin, 2016 recommends avoiding right angle in the raceway and too steep (> 20° or > 15° for heavy slaughter pigs) slopes and to keep the floor clean and non-slippery.

Dalla Costa et al., 2019a studied the effect of different group sizes of pigs (3, 5 and 10 pigs) during handling 360 pigs from five farms. Ease of handling decreased as the group size increased. Therefore, handling of small groups of pigs can prevent welfare impairment.

3.1.5.2. Welfare consequences 'Pain and Fear': assessment, hazard identification and management

Definition of 'Pain and Fear': see Section 3.1.3.2.

Moving animals forward to the stunning point is a very important source of pain and fear. To follow the speed of the slaughter-line, animals are often moved quickly through the raceway. The combination of higher speeds and poorly designed handling systems (i.e. slippery floors, with distractions that make animals balk, dark and bad maintained corridors, sharp edges...) is detrimental to animal welfare as handling animals at this rate requires considerable coercion and triggers the use of goads and sticks. Shocking pigs with electric goads results in pain and significantly raises heart rate, open mouth breathing and many other physiological indicators of acute distress (Dalmau and Velarde, 2017). The routine use of electric goads is also a sign of poor attitude of the stockperson.

When pigs are moved from the lairage place to the stunning point, if they have been injured previously, e.g. during transport or during a fight in lairage, or are suffering from lameness, they might experience pain. If the handling is not appropriate or the raceway not well designed and maintained (see Section 3.2 for description), then animals might experience fear and pain, not going smoothly into the raceway, turning back or refusing to move.

ABMs of 'Pain and Fear':

Animal-based measures that can be used during this process are the same as the ones used in the unloading process (see Section 3.1.3).

Pain and fear can be assessed by the measure of high-pitched vocalisations and reluctance to move in the raceway (for definition, see Section 3.1.3.2).

Additionally, pain can be assessed indirectly by the numbers of pigs showing injuries (and severity of injuries) and lameness. Vocalisation indicates both pain and fear since pigs are very prone to vocalise when they are scared, forced to do something they do not want or submitted to pain. Vocalisation is usually associated with electric goads use, excessive pressure from a restraint device, stunning problems or slipping on the floor (Grandin, 1997, 2001, 2017; Welfare Quality®, 2009; Rocha et al., 2016).

Escape attempt can also be an ABM for pain and fear, like during unloading.

Assessment of 'Pain' and 'Fear' during handling and moving of the animals can be done by counting the proportion of animals showing the ABMs reported in the following Table 17.

Table 17: ABMs for assessment of 'Pain and Fear' during handling and moving of the animals.

ABM	Description	Welfare consequence
Escape attempt	Attempts to move or run away from the situation (O'Malley et al., 2018)	Pain, fear
High pitched vocalisation	Squealing or screaming, at group level when pigs are moved or manipulated (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c).	Pain, Fear
Injuries	Tissue damage (bruises, scratches, broken bones, dislocations) (EFSA AHAW Panel, 2012a)	Pain
Lameness	Inability to use one or more limbs in a normal manner. It can vary in severity from reduced ability or inability to bear weight to total recumbency (Dalmau et al., 2009c; Welfare Quality®, 2009)	Pain
Reluctance to move	An animal that stops for at least 2 s not moving the body and the head (freezing) or that refuses to move when coerced by the operator (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c)	Fear
Turning back or turning around	When an animal facing towards the stunning area turns around and attempts to return to the lairage area (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c)	Fear

Hazards leading to consequences 'Pain and Fear':

The hazards are:

1) Improper design, construction and maintenance of premises
2) Rough handling (see Section 3.1.3.2)
3) Unexpected loud noise (see Section 3.1.3.2).

<u>Improper design, construction and maintenance of premises:</u>

In electrical stunning methods, when the animals should move from the lairage area to the stunning point, they generally should go from free-moving group through a raceway in a single line of aligned and restrained individuals. If the raceway is not well designed (lighting, presence of shadows, distractions) or maintained this could lead to fear and the reluctance of pigs to move, and hence, the operator resorting to rough handling causing pain.

Sharp contrasts, changes in lighting or light reflections in water puddles or on metal are frequent causes for animals to balk in abattoirs (Grandin, 2013). Grandin (2010) showed that insufficient light (less than 160–215 lux) at the entrance of the stunning area increased the use of electric goads by 34%. Refusal to enter dark environments or to cross shadows is potentially due to their inability to distinguish clearly their environment. Contrasts in colour on the floor and air current blowing towards approaching animals are also common cause of balking. Seeing people through the front of the box is also another reason for pigs to be reluctant to move.

Prevention and correction of 'Pain', 'Fear' and their related hazards

To design the raceway and behave correctly, it is crucial to understand how pigs explore, interpret and behave in their environment. Taking this into account, Grandin recommends as preventive measures to avoid distractions in the raceway such as: reflection or shiny metal, air blowing into the face of approaching animals, seeing people walking by or moving equipment, chain hanging, hoses on floor, coat on fence, high contrast walls or changes in flooring type, too dark entrance to stun box, restraint or raceway, flapping paper towels (Grandin, 2006, 2016).

Flags, paddles and plastic boards can be considered good alternatives to prevent the use of electric goads, although their effectiveness depends on the personnel using it (training and attitudes) and the design of the facilities, as mentioned above. In addition, it is recommended to move pigs in small groups (Dalla Costa et al., 2019a). Barton-Gade and Christensen (1998) suggested that pigs in group up to 15 are easier to move at unloading, during transfer to lairage pens and to the stunner. Ideally operators should be able to reach and directly handled all the animals in the group.

As a corrective measure, for example when pigs are backing all the time, it is not recommended to install anti back-up gates, but rather to remove the distractions listed above. Most of the time small adjustments can lead to important improvements. As a corrective measure, portable lights can be used at the entrance of a dark raceway to improve animal movement, and cardboard can be used to avoid approaching animals from seeing people (Grandin, 2016).

It has been recently observed that the use of green lighting reduces shadows on the floor and improve ease of handling through the alleys preventing stops and back-ups slowing down the flow of pigs towards slaughter (Eyes on Animals, 2019).

Hazards identified during 'Handling and moving of animals', relevant welfare consequences and related ABMs, origin of hazards, and preventive and corrective measures are reported in the following outcome table (see Section 3.1.5.3).

3.1.5.3. Outcome table on 'Handling and moving pigs to the stunning area'

Table 18: Outcome table on 'Handling and moving pigs to the stunning area'

Hazard	Welfare consequence/s occurring to the rabbits due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Improper design, construction and maintenance of premises (see Sections 3.1.5.1; 3.1.5.2)	Pain, fear, impeded movement	Staff, facilities, equipment	Improper conception (slope, right angles raceways), improper lighting (high contrast with bright and shades areas), lack of solid walls, distraction Poor daily management of the facilities (slippery and dirty floor)	• Ensure proper design, construction and maintenance of the area. • Rebuild the handling area regarding recommendation and animal behaviour	None
Rough handling (see Sections 3.1.5.1; 3.1.5.2)	Pain, fear; impeded movement	Staff, facilities	Lack of skilled operators Improper handling of animals; use of electric goads, rushing. Inability of the animals to go side by side.	• Training of staff for proper handling; appropriate equipment and facilities to move animals	Staff following recommendation to handle correctly pigs
Unexpected loud noise (see Section 3.1.5.2)	Fear	Staff, facilities, equipment	Staff shouting, machine noise, equipment noise	• Identify and eliminate the source of noise, staff training, avoid personal shouting	Identify and eliminate the source of noise

ABMs: injuries, lameness (pain), high pitched vocalisations (pain, fear), escape attempt, reluctance to move and turning back/around (fear), slipping, falling (impeded movement).

3.2. Description of Phase 2: Stunning

3.2.1. Introduction to stunning methods

Stunning is any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death. The stunning phase includes both the restraint and the stunning processes. In this perspective 'restraint' means the application to an animal of any procedure designed to restrict its movements sparing any avoidable pain and minimising fear in order to facilitate effective stunning and killing. Animals must be rendered unconscious and insensible by the stunning method and they must remain so until death occurs through bleeding. The main stunning methods employed in the slaughter of pigs are grouped into electrical, exposure to controlled atmospheres and mechanical. The methods, including the welfare consequences, animal-based measures, related hazards and preventive and corrective measures are described in Sections 3.2.1 to 3.2.9; the outcome table relevant to each method is reported in each relevant section.

Electrical stunning methods: The principle of electrical stunning is the application of sufficient current through the brain to induce generalised epileptiform activity in the brain, so that the animal becomes immediately unconscious and unable to feel pain (head-only electrical stunning Section 3.3.1). Head-only electrical stunning can be performed in combination with or immediately followed by passing an electrical current through the body to generate fibrillation of the heart or cardiac arrest (head-to-body stunning Section 3.2.3).

Controlled Atmosphere Stunning (CAS) methods: The principle of controlled atmosphere stunning is that animals are individually or in a small group exposed to CO_2 at high concentration, CO_2 mixed with inert gases or inert gases.

Mechanical stunning methods: The principle is the induction of brain concussion resulting in unconsciousness through the impact of a penetrative captive bolt or free projectiles or a hard object used to deliver a percussive blow to the head.

Mechanical methods are mainly used as backup method, or for small-scale slaughtering as in small abattoirs or on-farm slaughter.

Independently of the specific stunning method, the welfare consequences for phase 2 (stunning) are: pain, fear and respiratory distress. Therefore, differently from previous sections these three welfare consequences are presented below in the Sections 3.2.1.1. (pain and fear are presented together as they have same ABMs) and 3.2.2.2. (respiratory distress), while in the specific stunning methods sections only hazards and their management are presented.

3.2.1.1. Welfare consequences 'Pain' and 'Fear' and related ABMs

'Pain' and 'Fear' are defined in Section 3.1.3.2.

During phase 2, pigs might experience pain and fear during restrain (in electrical and mechanical methods) and during exposure to CAS before loss of consciousness.

Furthermore, ineffective stunning will lead to persistence of consciousness during hoisting, sticking and bleeding. Recovery of consciousness might occur in effectively stunned animals if sticking was delayed or was not properly done. Both these situations will also cause pain and fear to animals and are considered an important animal welfare concern in the stunning process.

Consciousness is defined as the capacity to receive, process and respond to information from internal and external environments and therefore the ability to feel emotions and being sensible to external stimuli, leading to pain and fear (Le Neindre et al., 2017). Therefore, in this phase, these welfare consequences are assessed through the presence of consciousness. For this reason, ABMs related to the presence of consciousness are described within the specific stunning method sections, and instead ABMs for pain and fear during restraint are described here.

In detail, ABMs related to pain during restraint are escape attempts, high pitched vocalisations and injuries. ABMs related to fear during restraint are escape attempts, high pitched vocalisations, reluctance to move and turning back.

For details, the ABMs related to restraint are described in full in the table below (Table 19).

Table 19: ABMs for assessment of 'Pain and fear' related to restraint during stunning

ABM	Description	Welfare consequence
Escape attempt	Attempts to move or run away from the situation (O'Malley et al., 2018)	Pain, fear
High pitched vocalisation	Squealing or screaming, when pigs are moved or manipulated (adapted from Welfare Quality®, 2009).	Pain, Fear
Injuries	Tissue damage (bruises, scratches, broken bones, dislocations) (EFSA AHAW Panel, 2012a)	Pain
Reluctance to move	An animal that stops at the entrance to the restraint for at least 2 s not moving the body and the head (freezing) or that refuses to move when coerced by the operator (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c)	Fear
Turning back or turning around	When an animal backs off while at the entrance of the restraint (adapted from Welfare Quality®, 2009; Dalmau et al., 2009c)	Fear

3.2.1.2. Welfare consequence 'Respiratory distress' and related ABMs

Respiratory distress is defined as the feeling of breathlessness, air hunger or chest tightness resulting in laboured or hampered breathing.

The main cause of respiratory distress is due to increased CO_2 levels (Raj, 2006), a strong respiratory stimulator that induces a sense of breathlessness and air hunger before loss of consciousness (Beausoleil and Mellor, 2015). It can also be induced by the lack of oxygen or hypoxaemia during stunning by inert gas mixtures (Beausoleil and Mellor, 2015); however, it has been less reported in the scientific literature.

Respiratory distress is shown by gasping or intense breathing (characterised by a very deep breath through a gaping-open mouth, indicative of breathlessness (Raj and Gregory, 1996; EFSA, 2004). Gasping will start before loss of consciousness and will persist for a certain time afterwards. Respiratory distress associated with air hunger or hypoxaemia is shown by increased breathing rates. Hyperventilation is defined as excessive breathing rates (Table 20). Pigs also show head shaking indicative of respiratory distress.

Table 20: ABMs for assessment of 'Respiratory distress' during exposure to CAS stunning

ABM	Description
Gasping	deep breath through a gaping-open mouth (Raj and Gregory, 1996; EFSA, 2004)
Hyperventilation	Excessive rate and depth of breathing (Raj and Gregory, 1996)
Head shaking	Rapid shaking of the head, most times accompanied by stretching and/or withdrawal movements of the head (EFSA, 2004)

3.2.2. Head-only electrical stunning

Head-only electrical stunning is based on the principle of passing an electric current of enough magnitude through the brain of the pig that induces a generalised epilepsy (see for details EFSA, 2004). The electrodes or stunning tongs can be applied manually or mechanically (Figure 9). The effectiveness of head-only electrical stunning depends upon two crucial factors. Firstly, the stunning electrodes (tongs) should be ideally placed on either side of the head, between the eyes and base of the ears, such that they span the brain. Secondly, the amount of current applied to the brain must be enough to induce immediate onset of epilepsy. For example, under the ideal tong position, a current of 0.5 A delivered using a 50 Hz sine wave alternating current (AC) would be sufficient, whereas, when the tongs are placed just behind the ears a current of 1.3 A would be necessary to stun pigs (Hoenderken, 1978; Anil, 1991). Under commercial conditions, it is not always easy to place the electrodes in the ideal position, and therefore, a minimum of 1.3 A is recommended when the electrodes are placed behind the ears. Furthermore, the voltage required to deliver this minimum current depends upon the frequency (Hz) of the electrical current.

Effective head-only electrical stunning induces loss of consciousness that is characterised by immediate collapse of the animal and tonic immobility during exposure to the stunning current. Immediately after exposure to the current, pigs show tonic seizure followed by clonic seizures, indicative of generalised epilepsy. Typically, during the tonic phase pigs are in a state of tetanus and stretch out their fore- and hind-legs, breathing is absent and the eyeballs are fixed or rotated into the socket. The tonic phase is followed by the clonic phase which manifests with kicking of legs, paddling or galloping movements (Berghaus and Troeger, 1998; Gregory, 1998; EFSA AHAW Panel, 2013).

Reflexes that would require brain control are also abolished during generalised epilepsy. For example, the palpebral (elicited by touching eyelashes or inner or outer canthus of the eye), corneal (elicited by touching the cornea) and pupillary (elicited by focusing bright Monitoring slaughter for pigs EFSA AHAW Panel, 2013 light into the pupil) reflexes and response to external stimuli including pain (e.g. nose prick) are also abolished during the period of unconsciousness (Anil, 1991). However, during epileptic-like seizure, the presence of corneal reflex is not indicating sensibility per se and can still be present or return when other signs of sensibility or consciousness are absent (Vogel et al., 2011). Brain stem reflexes such as the corneal reflex are difficult as measures of unconsciousness in electrically stunned animals, as they may reflect residual brain stem activity and not necessarily consciousness (Verhoeven et al., 2015).

Figure 9: Head-only electrical stunning using handheld stunning tongs (source IRTA)

Sticking or bleeding should be ideally performed during tonic phase (see Section 3.3 Bleeding for details). Effectively stunned pigs can recover consciousness rapidly following the termination of generalised epilepsy manifested as tonic–clonic seizures and it begins with the resumption of spontaneous breathing (Anil, 1991; Anil and McKinstry, 1998). Pigs will show positive eye reflexes and start to vocalise soon after resumption of breathing, and therefore, any animal showing spontaneous breathing should be re-stunned or a back-up method should be applied immediately.

3.2.2.1. Hazard identification

The hazards identified during this process are:

1) Restraint
2) Wrong placement of the electrodes
3) Poor electrical contact
4) Too short exposure time
5) Inappropriate electrical parameters.

These hazards can lead to the welfare consequence pain and fear during restraining and loading into restraining device and can lead after stunning to failure in onset of unconsciousness or to early recovery before or during bleeding.

Restraint:

An individual pig may be restrained manually or mechanically in order to present its head to the operator for the purpose of correct application of the stunning method.

Manual restraining methods, such as nose snare, boards or operator's legs, can be used to restrict the movement of pigs in small slaughterhouses with low throughput rates or during emergency slaughter of individual animals, whereas mechanical restraints in the form of 'V'-shaped conveyors (in which pigs are lifted off the floor and wedged between two conveyor belts) or monorails (in which the pigs are lifted off the floor and the monorail supports their body ventrally) are commonly used in high throughput slaughterhouses. Moving pigs from a group in lairage to a single line and restraining as individuals can be very stressful (Troeger, 1989). Moreover, moving animals from a group into a single line is in general addressed as the most critical part of the process at high slaughter speed and is an important motivation for the slaughterhouse to justify CAS in pigs. Critical factors at this point are the entrance into the raceway and the 'stop-start'' motion of pigs towards the stunner due to the flip-flop gate between two raceways allowing pigs one by one onto the restraining conveyor. The level of pain and fear caused at this point strongly depends on the force used on the animals to move them forward.

Nevertheless, pigs are stress susceptible animals and restraining them can be a stressful process (Griot et al., 2000; Rosochacki et al., 2000). Animals in restraint should be stunned without delay.

Wrong placement of the electrodes:

The position of the head-only stunning electrodes does not span the brain to induce immediate unconsciousness.

Variations in the placement of stunning electrodes have been reported to be a major welfare concern during manual electrical stunning of pigs without any form of restraint (Anil and McKinstry, 1998). In the worst-case scenario, in spite of good electrical contact the electrodes fail to deliver current flow through the brain because they are positioned far away from the head, e.g. base of the neck. More recently, Stocchi et al. (2014) carried out a survey of pig slaughterhouses in Italy and reported that wrong placement of electrodes was observed in 54.0% of the animals. Nodari et al. (2014) also reported wrong placement of electrodes being a major hazard during manual stunning of pigs.

Poor electrical contact:

The electric contact between the animal and stunning electrodes is not sufficient to facilitate current flow necessary to achieve immediate stunning. Poor electrical contact can occur due to the presence of dense hair at the electrode position or due to uneven bone surface in the temporal region of the skull of some animals.

Nevertheless, a study funded by DEFRA (DEFRA, 2005) illustrated that the pressure applied during the application of stunning, i.e. how hard the stunning tongs were pressed against the head, is important to ensuring good electrical contact and it should be maintained during the entire duration of stunning. It is worth noting that, based on the results of preliminary studies carried out in this project, a pressure of 25 kg was chosen as optimum to evaluate efficacy of head-only stunning pigs using different voltages and frequencies.

Maintaining a constant pressure during stunning is essential to maintain good electrical contact and hence the current flow through the tissues in the pathway. Regular cleaning of the electrodes using a wire brush and maintenance and calibration of the stunner improves effectiveness of stunning (EFSA, 2004; Grandin, 2012).

Too short exposure time (stun duration):

The duration of exposure to the electrical current is too short to result in epileptiform activity in the brain. This hazard can occur either due to time pressure (high throughput rate) or when the electrodes lose contact with the animal during manual stunning as operator error.

It has been reported that when head-only electrical stunning is applied with 1.3 A using a constant current stunner, a minimum current flow time of 0.3 s is necessary to induce epilepsy in the brain (Berghaus and Troeger, 1998). The duration of the period of unconsciousness depends of the amount of current delivered to the brain and exposure time. It is recommended to deliver the current for at least 2–3 s to produce a state of unconsciousness, which will persist until death occurs through bleeding (EFSA, 2004).

Inappropriate electrical parameters:

The electrical parameters (current, voltage and frequency) are not adequate to induce immediate loss of consciousness and/or death.

Several factors can contribute to this hazard (see Outcome table in Section 3.2.2.4). In particular, wrong choice of electrical parameters, too low applied voltages or current unable to overcome the electrical impedance/resistance in the pathway, lack of calibration of equipment, lack of monitoring of stun quality and lack of adjustment to the settings to suit different animal types (e.g. slaughter weight pigs vs. boars and sows). Several factors contribute to the electrical resistance/impedance recorded between the stunning electrodes, especially dry skin and density of bones, dirty electrodes (EFSA, 2004).

Research has shown that the impedance to stunning current flow is a function of the applied voltage (decreasing with increasing voltage). For example, Wotton and O'Callaghan, 2002, demonstrated that the impedance of a live (anaesthetised) pig's head was predominantly a function of the stunning voltage and decreased non-linearly with increasing voltage used to stun the animal. It was suggested that the applied voltage should be high enough (e.g. minimum 240V) to breakdown the impedance rapidly and produce an immediate stun (Figure 10).

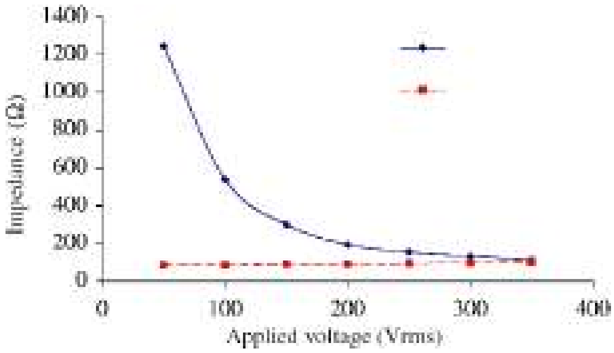

Figure 10: The effect of voltage magnitude on impedance to current flow (anaesthetised pigs) recorded using windup (blue line)/wind-down (red line) technique

Another study funded by DEFRA (DEFRA, 2005) in the UK demonstrated that the minimum voltage at 50 Hz that will produce a 97.5% chance of reaching 1.3 A within 0.2 s is 250 volts and that the minimum voltage at 1,500 Hz that will produce a 97.5% chance of reaching 1.3 amps within 0.2 s is 350 volts. Evidently, the minimum voltage required to delivering 1.3 amps increases with increasing frequency of the stunning current. Nevertheless, a minimum stun duration of 3 s is recommended.

Stocchi et al. (2014) carried out a survey of pig slaughterhouses in Italy and reported that 84.13% of animals showed one or more signs of consciousness during bleeding and insufficient voltage/low stunning currents were found to be the main cause. Nodari et al. (2014) also reported low voltage/current being a major hazard leading to ineffective stunning or recovery of consciousness during bleeding.

3.2.2.2. Animal-based measures (ABMs) in the context of 'Head-only electrical stunning'

During the restraining, the welfare consequences are pain and fear. After stunning, if the stunning is ineffective or if the animals recover consciousness, the welfare consequences are pain and fear due to persistence of consciousness. Therefore, consciousness is not a welfare consequence per se but a prerequisite for experiencing pain and fear.

ABMs related to pain and fear after stunning are the signs of state of consciousness, which have to be checked through the three key stages of monitoring during the slaughter process: after stunning (between the end of stunning and hoisting), during sticking (cutting brachiocephalic trunk) and during bleeding. The assessment of the state of consciousness leads to two possible outcomes: outcomes of consciousness and outcomes of unconsciousness.

In case outcomes of consciousness appears after stunning, appropriate back-up stunning method should be applied immediately to mitigate the welfare consequences.

ABMs related to the state of consciousness were selected in a previous opinion (EFSA AHAW Panel, 2013) and are described in full in the table below (Table 21).

Table 21: ABMs for assessment of 'State of consciousness' after Head-only electrical stunning.

ABMs	Description
Tonic/clonic seizures	Effective head-only electrical stunning leads to the onset of tonic–clonic seizures soon after immediate collapse of the animal. The tonic seizure, which may be recognised from the tetanus, lasts for several seconds and is followed by clonic seizures lasting for seconds and leading to loss of muscle tone (EFSA AHAW Panel, 2013)
Breathing	Effective electrical stunning will result in immediate onset of apnoea (absence of breathing). Ineffectively stunned animals and those recovering consciousness will start to breath in a pattern commonly referred to as rhythmic breathing, which may begin as regular gagging and involves respiratory cycle of inspiration and expiration Rhythmic breathing can be recognised from the regular flank and/or mouth and nostrils movement. Recovery of breathing, if not visible through these movements, can be checked by holding a small mirror in front of the nostrils or mouth to look for the appearance of condensation due to expiration of moist air (EFSA AHAW Panel, 2013)
Palpebral and/or corneal reflex	The palpebral reflex is elicited by touching or tapping a finger on the inner/outer eye canthus or eyelashes. Correctly stunned animals will not show a palpebral reflex. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus The corneal reflex is elicited by touching or tapping the cornea. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus. Unconscious animals may also intermittently show a positive corneal reflex (EFSA AHAW Panel, 2013)
Spontaneous blinking	Conscious animals may show spontaneous blinking, and therefore, this sign can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all the conscious animals may show spontaneous blinking (EFSA AHAW Panel, 2013)
Posture	Effective head-only electrical stunning will result in immediate collapse or loss of posture in animals that are not restrained or prevented from doing so. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse (EFSA AHAW Panel, 2013)
Vocalisations	Conscious animals may vocalise, and therefore purposeful vocalisation can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all conscious animals may vocalise (EFSA AHAW Panel, 2013)
Muscle tone	Head-only electrically stunned animals will show general loss of muscle tone after the termination of tonic–clonic seizures coinciding with the recovery of breathing and the corneal reflex if not previously stuck. Loss of muscle tone can be recognised from the completely relaxed legs, floppy ears and tail and relaxed jaws with protruding tongue. Ineffectively stunned animals and those recovering consciousness will show a righting reflex and attempts to raise the head (EFSA AHAW Panel, 2013)

For head-only electrical stunning, EFSA AHAW Panel (2013) suggested the following flowchart (Figure 11), where ABMs to monitor the state of consciousness are suggested and included in toolboxes (blue boxes in Figure 11), to be used at three key stages. For each key stage, three ABMs that are reliable in monitoring consciousness are suggested (above the dashed line), plus other two or three ABMs, which are less reliable, that can be additionally used (below the dashed line). For each ABM, corresponding outcomes of consciousness and unconsciousness are reported (EFSA AHAW Panel, 2013).

In case outcomes of consciousness are observed in key stage 1, then an intervention should be applied (i.e. a backup method). After any reintervention, the monitoring of unconsciousness, according to the flowchart, should be performed again. Only when outcomes of unconsciousness are observed the process can continue to the next steps. Following key stage 3, in case outcomes of life are observed an intervention should be applied; only when outcomes of death are observed, the animals can be processed further.

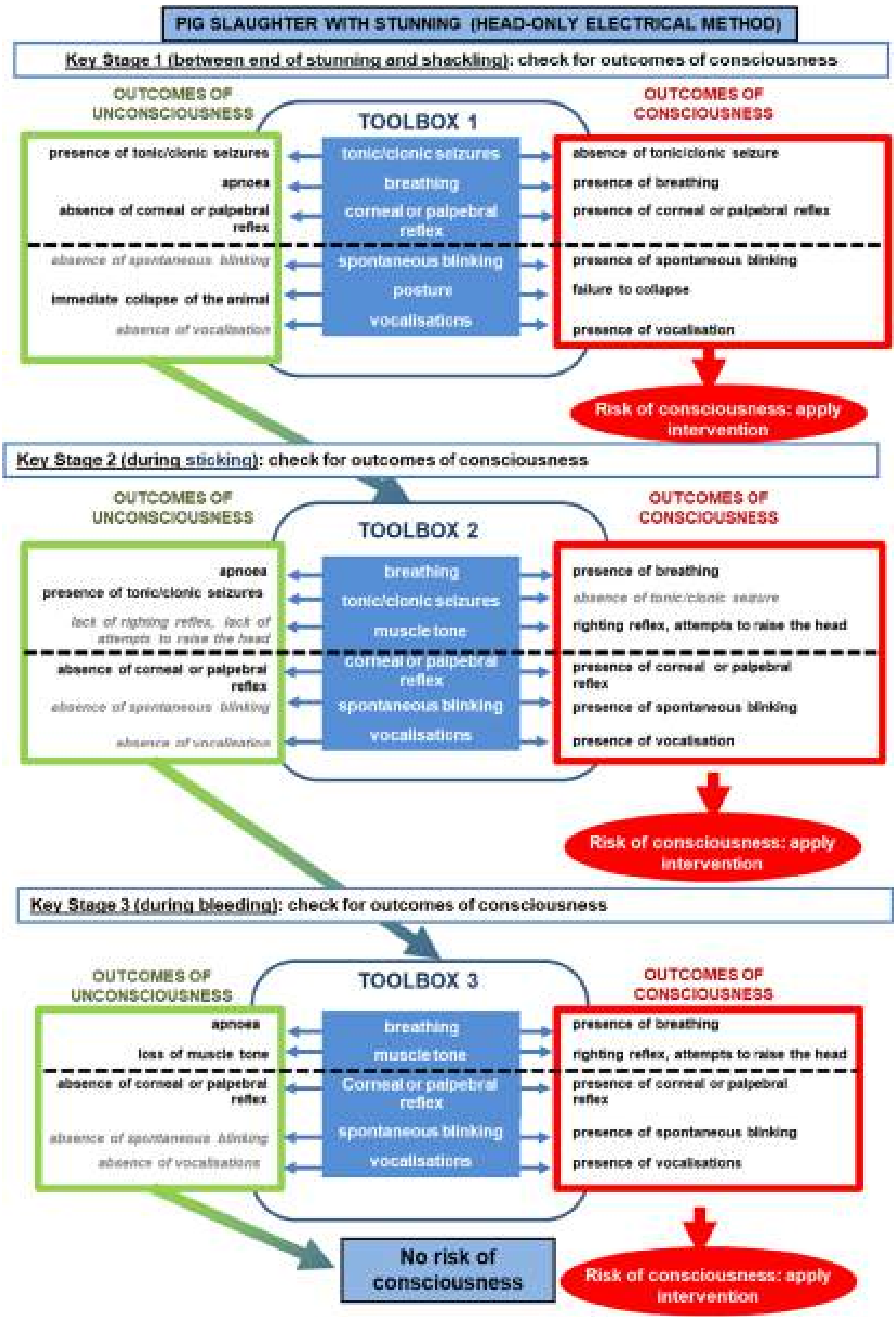

Figure 11: Flowchart including indicators for the monitoring of state of consciousness (EFSA AHAW Panel, 2013)

3.2.2.3. Prevention and correction of welfare consequences and their related hazards

Pain and fear during restraint and application of head-only electrical stunning should be prevented through adequate design and maintenance of the restraining and stunning equipment and staff competence and training. Animals must be restrained only when the stunning can be performed without any delay. Animals should not be left in restrainers during work breaks, and in the event of a breakdown animals should be removed from the restraint promptly. Moving a group of animals into a single line at the commercial slaughter speed is a challenging procedure. The use of too much pressure, shouting, hitting or the use of (electric) goads to force the animals from a group into a single line raceway will lead to fear and resistance of the animals. The result will be that animals are reluctant to move.

Design of the raceway like a carousel or curved raceways can facilitate the flow of the pigs (Grandin, 1990; Jones, 1999) and therefore reduce the level of pain and fear. It is also important to note that the restraint should be adjusted to suit pigs of different sizes and weight range to minimise pain and fear. The raceways and entrance to the restraint should not have sharp edges and should be always clean to maintain movement of animals without the need to use force and avoid animals slipping and falling (Grandin, 2012).

Reducing the loading speed and giving animals the time and opportunity to go from a group into a single line will prevent or reduce the level of fear and stress. Limiting the space to move away or escape from the stunning method by using boards, walls or operator's legs will help to reduce fear and pain. Using adequate driving materials like peddles or clappers will prevent painful interactions with the animals like when using (electric) goads.

Only restraining methods that are optimal according to the size of the animal should be used. Methods that are painful by the application itself like nose snare should be avoided.

Owing that pigs are stress susceptible animals and restraining them can be a stressful process, duration of restraint should be as short as possible and, as a guide to good practice, animals should not be restrained until the operator(s) is not ready to stun and bleed them. In addition, the width of the restraint should be appropriate for the size of the animals and loading of animals into the restraint should be done smoothly.

Staff should be trained to acquire adequate knowledge and skills to understand the behaviour of pigs and the need for optimum restraint required for stunning or adjusting restraint according to the size of the animal.

The stunning equipment should ensure correct size of the stunning electrodes according to the size of the animals. The stunner should be equipped with a built-in timer monitoring exposure time or visual or auditory warning system to alert the operator.

Staff should be trained for correct placement of the stunning electrodes, maintaining adequate pressure, continuous contact between the animal and electrodes and use of current necessary to achieve effective stunning appropriate to the waveform and frequency. Slowing down the process will help to prevent or minimise the incidence of some of the hazards, if high throughput is the cause.

Regular cleaning of electrodes using a wire brush, calibration and maintenances of the equipment is essential to prevent hazards that might lead to ineffective stunning.

Inadequate stunning should be corrected by application of an adequate back-up procedure. For this purpose, staff should be trained to recognise signs of ineffective stunning by continuous monitoring and identify causes of failures such as high electrical resistance/impedance.

Regular auditing of the effectiveness of stunning by assessing incidence of wrong electrode placement or of the number of animals vocalising as consequence of poor placement will help to implement appropriate prevention/correction measures (Grandin, 2010).

3.2.2.4. Outcome table on 'Head-only electrical stunning'

Table 22: Outcome table on 'Head-only electrical stunning'

Hazard (see Section 3.2.2.1)	**Welfare consequence/s occurring to the pigs due to the hazard**	**Hazard origin/s**	**Hazard origin specification**	**Preventive measure/s for the hazard (implementation of SOP)**	**Corrective measure/s for the hazard**
Restraint	Pain, fear	Staff	Presentation of pigs to the method is required in some systems	• Use optimal restraint according to the size of the animal • Use boards, side walls or operator legs to limit space • Don't use nose snares	None
Wrong placement of the electrodes	Pain, fear	Staff, equipment	Too high throughput rate, Inadequate calibration/ adjustment of the equipment to suit the size of pigs Lack of skilled operator Improper or lack of restraint	• Reduce throughput rate • Adjust / synchronise the equipment • Staff training • Appropriate restraint	Stun using correct placement or use a backup method
Poor electrical contact	Pain, fear	Staff, equipment	Lack of skilled operators, staff fatigue; incorrect placement of the electrodes; poorly designed, constructed and maintained equipment; intermittent contact	• Staff training; staff rotation; ensure correct presentation of the pigs, ensure correct maintenance of the equipment; ensure the equipment includes electrodes for different sized animals; ensure continuous contact between the electrodes and the pigs; ensure regular calibration of equipment, regular cleaning of the electrode with a wire brush	Stun using correctly or use a backup method
Too short exposure time	Pain, fear	Staff,	Lack of skilled operators, high throughput rate	• Staff training; reduce throughput rate; ensure a timer is built in the stunner to monitor the time of exposure or use of a visual or auditory warning system to alert the operator	Stun using correct exposure time or use a backup method

Hazard (see Section 3.2.2.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Inappropriate electrical parameters	Pain, fear	Staff, equipment	Wrong choice of electrical parameters or equipment; poor or lack of calibration; voltage/current applied is too low; frequency applied is too high for the amount of current delivered; lack of skilled operators, lack of monitoring of stun quality; lack of adjustments to the settings to meet the requirements Poor maintenance and cleaning of the equipment	• Use parameters appropriate to the frequency and waveforms of current; ensure the voltage is sufficient to deliver minimum current; regular calibration and maintenance of the equipment; staff training; consider the factors contributing to high electrical resistance and minimise-eliminate the source of high resistance; monitor stun quality routinely and adjust the equipment accordingly; use constant current source equipment; use wire brush to clean tongs regularly	Stun using correct parameters or use a backup method

ABMs: injuries (pain), high pitched vocalisations, escape attempts (pain, fear), reluctance to move, turning back and turning around (fear), outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.2.3. Head-to-body electrical stunning

Head-to-body stunning can be performed using a single current cycle in which electrodes are placed on either side of the head to induce unconsciousness and a third electrode is placed on the chest to induce cardiac ventricular fibrillation (Figure 12), which is common in high throughput slaughterhouse. On the other hand, a two current cycle application may be used which involves head-only electrical stunning immediately followed by a second current application across the chest (behind the elbow) to induce cardiac ventricular fibrillation. Generally, a two-cycle head-to-body stunning is performed by manual placement of stunning tongs on the head to render the animal unconscious followed by placing the electrodes on the chest to pass a current through the heart to induce ventricular fibrillation. Irreversible stunning of pigs by head-to-body application of an electric current eliminates the chances of recovery of consciousness and stun-to-stick interval is not critical. Therefore, this method is considered to be better on animal welfare grounds. For this to occur, head-to-body stunning should always be performed using a 50 Hz sine wave alternating current (AC), as higher frequencies do not induce cardiac ventricular fibrillation.

Vogel et al. (2011) investigated the efficacy of head-only stunning for 3 s immediately followed by application of the same stunning electrodes to the cardiac region of the animal for 3 s while lying in lateral recumbency. Based on the results, it was concluded that the two-cycle method reduced the incidence of recovery of consciousness following stunning without significant effects on meat quality or slaughterhouse operation speed.

Nodari et al. (2014) reported that head-to-body automatic stunning in a pig slaughterhouse involving application of on average 2.5A across the head and 1.0 A between the head and chest electrodes resulted in the best animal welfare outcomes with none of the animals showing signs of consciousness.

Figure 12: Head-to-body electrical, stunning/killing (three points) and restraining system (source: Virginie Michel)

Effective head-to-body electrical stunning is characterised by tonic immobility during exposure to the stunning method. After exposure, pigs show tonic seizure followed by clonic convulsions comparable as described for head-only electrical stunning. The convulsive movements will change to paddling movements and relaxation and loss of muscle tone recognised by drooping ears and limp legs. Breathing is absent and eyes are fixed or rotated in their sockets. Corneal and palpebral reflex are abolished and reaction to pain stimuli are absent during the period of unconsciousness (see process description head only electrical stunning).

However, during manual stunning involving two electric current cycle method, the time interval between the two applications is critical. Head-only electrical stunning leads to immediate collapse of the animal and onset of tonic–clonic seizures and these may impede with the application of second current cycle across the chest to induce cardiac ventricular fibrillation. Therefore, additional care should be taken to apply the second cycle before the effectively stunned animals recover consciousness, which can be recognised from the resumption of spontaneous breathing.

3.2.3.1. Hazard identification in the context of 'head-to-body electrical stunning'

Hazards leading to 'Pain and fear':

The hazards identified during this process are:

1) Restraint
2) Wrong placement of the electrodes
3) Poor electrical contact
4) Too short exposure time
5) Inappropriate electrical parameters.

These hazards can cause pain and fear and can lead to failure in the onset of unconsciousness or to early recovery before or during bleeding.

Figure 13: Pigs being forced in a single line raceway to enter the automated electrical stunning method (Source: Virginie Michel)

Restraint:

Head-to-body electrical systems are usually running in high throughput slaughterhouses (Figure 13), whereas, mechanical restraints in the form of 'V'-shaped conveyors or monorails are commonly used (see head-only section).

In small slaughterhouses with low throughput rates or during emergency slaughter of animals, head-to-body stunning might be applied with the same set of electrodes that for head-only. In this case, the stunning tongs are placed manually on the head and across the chest, and manual restraining methods, boards or operator's legs can be used to restrict the movement of pigs like for head-only stunning.

Wrong placement of electrodes:

The position of the head-only stunning electrodes does not span the brain to induce immediate unconsciousness and/or the second current cycle applied across the chest to induce cardiac arrest in unconscious animals does not span the heart, or the head-to-body stunning electrodes does not span the brain and/or the heart. Another hazard related to pain will be if the second cycle spans the heart in conscious animals.

This hazard usually occurs under manual stunning systems (Nodari et al., 2014; Stocchi et al., 2014). However, it can occur in automatic stunning systems also if the equipment is not adjusted to the size of the animals.

(See corresponding text under head-only electrical stunning also).

Poor electrical contact:

The electric contact between the animal and stunning electrodes is not enough to facilitate current flow necessary to achieve immediate stunning and ventricular fibrillation.

(See corresponding text under head-only electrical stunning also).

Too short exposure time:

The duration of exposure to the electrical current is too short to result in epileptiform activity in the brain and/or cardiac arrest.

High line speeds resulting in high throughput rates in the automated head-to-body stunners can lead to inadequate or too short contact with the electrodes.

(See corresponding text under head-only electrical stunning also).

Inappropriate electrical parameters:

The electrical parameters (current, voltage and frequency) are not adequate to induce immediate loss of consciousness and/or death.

The current cycle intended to induce cardiac arrest must always be delivered using 50 Hz sine wave alternating current of enough magnitude.

Several factors can contribute to this hazard (see Outcome Table in Section 3.2.3.4). In particular, wrong choice of electrical parameters, too low applied voltages or current unable to overcome the electrical impedance/resistance in the pathway, lack of calibration of equipment, lack of monitoring of stun quality and lack of adjustment to the settings to suit different animal types (e.g. slaughter weight pigs vs. boars and sows).

The European Commission Regulation stipulates that a minimum stunning current of 1.3 amps must be delivered for head-to-body electrical stunning using a constant current source.

3.2.3.2. Animal-based measures (ABMs) in the context of 'head-to-body electrical stunning'

During the restraining, the welfare consequences are pain and fear. After stunning, if the stunning is ineffective or if the animals recover consciousness, the welfare consequences are pain and fear due to persistence of consciousness. Therefore, consciousness is not a welfare consequence per se but a prerequisite for experiencing pain and fear.

ABMs related to pain and fear during restraint and loading into the restraining device are high pitched vocalisations, escape attempts and injuries (see details in Table 19, Section 3.2.1.1).

ABMs related to pain and fear after stunning are the signs of state of consciousness, which have to be checked through the three key stages of monitoring during the slaughter process: after stunning (between the end of stunning and hoisting), during sticking (cutting brachiocephalic trunk) and during bleeding.

The same signs of state of consciousness that are in the flowchart for head-only electrical stunning were retrieved from the scientific literature and are therefore suggested for head-to-body electrical stunning (see table of ABMs: Table 21, and flowchart in Section 3.2.2.2).

3.2.3.3. Prevention and correction of welfare consequences and their related hazards

Pain and fear due to restrain and application of head-to-body electrical stunning can be prevented through adequate design and maintenance of the restraining and stunning equipment and staff competence and training (see section of head-only electrical stunning).

3.2.3.4. Outcome table on 'head-to-body Electrical stunning'

Table 23: Outcome table on 'head-to-body Electrical stunning'

Hazard (see Section 3.2.3.1)	Welfare consequence/s occurring to the rabbits due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Restraint	Pain, fear	Staff and equipment	Presentation of pigs to the method is required	• Use optimal restraint according to the size of the animal	None
Wrong placement of the electrodes	Pain, fear	Staff, equipment	Too high throughput rate, Inadequate calibration/ adjustment of the equipment to suit the size of pigs Lack of skilled operator Improper or lack of adequate restraint	• Reduce throughput rate • Adjust/synchronise the equipment • Staff training • Appropriate restrain	Stun using correct placement or use a backup method
Poor electrical contact	Pain, fear	Staff, equipment	Lack of skilled operators, staff fatigue; poorly designed, constructed and maintained equipment; intermittent contact Incorrect setting of automatic stunner to fit the size of the pig	• Staff training; staff rotation; ensure correct presentation of the pigs, ensure correct maintenance of the equipment; ensure the equipment includes electrodes for different sized animals; ensure continuous contact between the electrodes and the pigs; ensure regular calibration of equipment, regularly clean electrodes using a wire brush • Slow down the process	Stun the animal correctly or use a backup method
Too short exposure time	Pain, fear	Staff, equipment	Lack of skilled operators, high throughput rate;	• Staff training; reduce throughput rate; ensure a timer is built in the stunner to monitor the time of exposure or use of a visual or auditory warning system to alert the operator	Stun using correct exposure time or use a backup method

Hazard (see Section 3.2.3.1)	Welfare consequence/s occurring to the rabbits due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Inappropriate electrical parameters	Pain, fear	Staff, equipment	Wrong choice of electrical parameters or equipment; poor or lack of calibration; voltage/current applied is too low; frequency applied is too high for the amount of current delivered; lack of skilled operators, lack of monitoring of stun quality; lack of adjustments to the settings to meet the requirements	• Use parameters appropriate to the frequency and waveforms of current; ensure the voltage is sufficient to deliver minimum current; regular calibration and maintenance of the equipment; staff training; consider the factors contributing to high electrical resistance and minimize-eliminate the source of high resistance; monitor stun quality routinely and adjust the equipment accordingly; use constant current source equipment	Stun using correct parameters or use a backup method

ABMs: injuries (pain), high pitched vocalisations, escape attempts (pain, fear), reluctance to move, turning back and turning around (fear), outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.2.4. Controlled atmosphere stunning method 1: CO_2 at high concentrations

CO_2 at high concentration for pigs normally implies the direct exposure of conscious animals to a gas concentration of more than 80% CO_2.

Under commercial conditions, the commonly used method is by lowering individuals or small groups of pigs in a gondola (see Figure 14) into a well that is pre-filled with a high concentration of more than 80% CO_2 (Atkinson et al., 2012). The system can be operated with mechanical push gates that separate a large group of pigs into groups of five or six and move them into the stun cage. This method has some animal welfare advantages compared with electrical stunning, as animals are stunned in groups with the minimum amount of restraint and handling stress (Velarde et al., 2000; EFSA, 2004).

The fact that pigs do not need to be individually restrained and can be stunned in a group is considered a major benefit in terms of animal welfare in comparison with automated electrical stunning methods. (see hazard during head-to-body electrical stunning).

In the presence of normal atmospheric air (absence of a high CO_2 concentration), the process of entering the cage and pigs being lowered into the pit or moved within the tunnel does not cause aversion (Velarde et al., 2007; Dalmau et al., 2010). Two main systems exist, the dip-lift system and the paternoster system. Dip-lift designs have only one cage in the system that can be loaded with a nominal capacity of six pigs. In this system, groups of pigs are lowered directly into maximum concentrations of CO_2 at the bottom of the pit (EFSA, 2004). The paternoster designs have up to seven cages (a nominal capacitytwo to six pigs per cage), rotating through the CO_2 gradient in a 3- to 8-m deep pit, stopping at various intervals for loading of live pigs on one side and unloading unconscious pigs on the other side for sticking (EFSA, 2004). The number of pigs per group, the time taken to reach maximum CO_2 concentrations and total exposure times are manipulated by the individual abattoirs according to their own discretion (Atkinson et al., 2012). The space allowance in the cage shall be enough to allow the animals to lie down without being stacked even at maximum permitted throughput. Stunning equipment is fitted with devices displaying and recording the gas concentration and the time of exposure and giving alarms in case of insufficient gas concentration.

Figure 14: Loading of a group of pigs in a gondola (Source: Antonio Velarde)

Pigs are immersed into a concentration gradient of the gas, such that, as the cage is lowered into the pit, the CO_2 concentration continues to rise until it reaches 80–90% at the bottom of the well (EFSA, 2004). Under commercial conditions, the concentration of CO_2 should be at least 80%, but more and more slaughterhouse use 90% or higher in an attempt to increase throughput rates (Velarde et al., 2007) and guarantee effective stun duration.

Exposure of pigs to CO_2 leads to metabolic acidosis (reduction in blood pH; Mota-Rojas et al., 2012) and, as a consequence, significant reduction in the pH of the cerebrospinal fluid bathing the brain, which, in turn, induces gradual loss of consciousness and sensibility through inhibition of the spontaneous brain activity (Rodríguez et al., 2008). The neurophysiological basis and the consequences of brain inhibition are well documented in the scientific literature (see EFSA, 2004 for details). The survival time of different regions of the brain and the spinal cord following exposure to CO_2 varies. Therefore, a prolonged exposure to high concentration of CO_2 (> 80% by volume in air) would be necessary to prevent recovery of consciousness and sensibility during hoisting, sticking and bleeding (Rodríguez et al., 2008; Llonch et al., 2012c). Under batch or group stunning situations, the duration of unconsciousness and insensibility becomes more critical because the time interval between the end of exposure to the gas and sticking (stun-to-stick interval) would be considerably longer for the last animal in a group (Raj, 1999; Atkinson et al., 2012). Bolanos-Lopez et al. (2014) suggested that bleeding should be performed as soon as possible after pigs exiting the gas.

Pig stunning with a high concentration of CO_2 can be reversible (simple-stunning) or irreversible. The depth and duration of unconsciousness achieved with CO_2 gas stunning depend upon the animal, the CO_2 concentration, the speed at which animals are lowered towards the bottom of the pit, where the highest CO_2 concentration is achieved, and the duration of exposure (Troeger and Woltersdorf, 1991; Raj and Gregory, 1996). Sticking must start as soon as possible after stunning to prevent resumption of consciousness. If not possible, the stun-stick interval can be increased proportionally without animals recovering consciousness, through increased exposure time to the gas (Holst, 2001). Prolonged exposure may result in irreversible stunning and eliminate the chances of recovery of consciousness. Exposure of pigs to a minimum of 90% by volume of CO_2 in air for 3–5 min results in death of most of the pigs at the exit from the gas.

The rate of induction, depth and duration of unconsciousness induced with gas mixtures depends on both exposure time and gas concentration. Higher concentrations of CO_2 require shorter exposure times to induce an adequate level of unconsciousness than lower CO_2 concentrations (Verhoeven et al., 2016). Exposure times and gas concentrations are, therefore, two crucial parameters to control during gas stunning.

The earliest sign of onset of unconsciousness and insensibility during exposure of pigs to high concentrations of CO_2 is the loss of posture (Verhoeven et al., 2015). Field observations of gas stunning suggest that it may not always be possible to determine the exact time to loss of posture as pigs start to show excessive movements prior to loss of posture (frequently described as the excitation phase). However, as exposure to a gas mixture continues, these convulsions stop, leading to a complete loss of muscle tone. There is also a suppression of respiration, which can be evidenced from progressively declining rate and depth of breathing, resulting in complete cessation of any respiratory activity, including gagging at the exit of the chamber (Raj, 1999). Other signs of unconsciousness induced by exposure to high concentrations of CO_2 include fixed eyes, dilated pupil, absence of the palpebral (elicited by touching eyelashes or inner or outer canthus of the eye), corneal (elicited by touching the cornea) and pupillary (elicited by focusing bright light into the pupil) reflexes and absence of response to painful stimuli such as nose prick or ear pinch (Raj, 1999; Rodríguez et al., 2008). In addition, Rodríguez et al. (2008) reported that 82% of the animals exposed to a high concentration of CO_2 did not show a corneal reflex at the exit of the stunner. However, the remaining 18% of the animals lost corneal reflex only 18 s after the exit from the stunner. Brain stem reflexes like the corneal reflex are the last reflexes that will abolish in the process of inducing deep unconsciousness. In case corneal reflex is the only reflex that is still present, it will not indicate consciousness or sensibility (Verhoeven et al., 2015).

3.2.4.1. Hazard identification in the context of 'Controlled atmosphere stunning method 1: CO_2 at high concentrations'

Hazards leading to 'Pain, fear and respiratory distress':

The hazards identified during this process are:

1) Exposure to high CO_2 concentrations
2) Too short exposure time
3) Too low concentration of gas
4) Overloading of the gondola
5) Too low temperature of the gas.

These hazards can cause pain, fear and respiratory distress during the induction to unconsciousness and can lead to failure in onset of unconsciousness or to early recovery before or during bleeding.

<u>Exposure to high CO_2 concentrations:</u>

It has been demonstrated that pigs find CO_2 in high concentrations aversive and, given a free choice, they avoid such atmospheres (Raj and Gregory, 1995; EFSA, 2004). CO_2 itself causes irritation of the nasal mucosa and exposure is therefore inducing a painful sensation (Steiner et al., 2019). CO_2 has the potential to cause welfare consequences via three different mechanisms: (1) pain due to formation of carbonic acid on respiratory and ocular membranes, (2) production of so-called air hunger and a feeling of breathlessness and (3) direct stimulation of ion channels within the amygdala associated with the fear response (Raj, 2006; Beausoleil and Mellor, 2015; AVMA, 2020).

The degree of aversion depends on the CO_2 concentration. Velarde et al. (2007) reported that the aversion was higher when the stunning system contained 90% as opposed to 70% CO2 due possibly to increased irritation of the nasal mucosal membranes (pain and fear) and more severe respiratory distress (Raj and Gregory, 1996). Conversely, a decrease in the concentration of CO2 increased the time to onset of unconsciousness as determined using time to loss of posture and, therefore, lengthened the perception of the aversive stimulus till the animal lost consciousness. Immersion of pigs into 80–90% CO_2 usually leads to the induction of unconsciousness within 30 s.

Becerril-Herrera et al. (2009) also concluded that CO_2 stunning leads to a major imbalance because of mineral and acid base gaseous interchange, compared to electric stunning, thus possibly compromising animal welfare.

Too short exposure time:

During exposure to CO_2 at high concentration loss of consciousness is not immediate, and the induction of unconsciousness and depth of unconsciousness depends on the CO_2 concentration as well as on the duration of exposure (Nowak et al., 2007). When the duration of exposure is too short, animals will recover consciousness before or during bleeding. The lower the CO_2 concentration the longer the time to induce unconsciousness (see EFSA, 2004 for details).

Too low concentration of gas:

The gas concentration is too low to render pigs unconscious within the applied time of exposure or to prevent recovery of consciousness during bleeding (see EFSA, 2004 for details).

Low CO_2 concentrations will prolong the induction of unconsciousness, leading to prolonged respiratory distress (Raj and Gregory, 1996).

Too low temperature of the gas:

Administration of liquid or solid CO_2 into the chamber due to the lack of vaporisation will drop the environmental temperature. Inhalation of dry cold gas can cause pain to the pigs. Liquid CO_2 needs an external heat source to vaporise to the ambient temperature.

Overloading of the gondola:

Exceeding the capacity of the equipment in terms of number of pigs that can be loaded into the gondola with available floor space leading to inadequate exposure to the gas in some pigs.

Overloading increases the risk of unnecessary excitement and may lead to bruising increases.

In a group stunning situation, overloading of the gondola may lead to animals falling on top of each other, and as a consequence, compression of the chest of animals at the bottom of the pile; these animals may not have adequate exposure to gas mixtures and hence suffer poor animal welfare outcomes.

3.2.4.2. Animal-based measures (ABMs) in the context of 'Controlled atmosphere stunning method 1: CO_2 at high concentration'

During exposure to CO_2 at high concentrations, ABMs related to pain, fear and respiratory distress are associated with excitation behaviour, retreat and escape attempts and gasping (Raj and Gregory, 1996; Velarde et al., 2007; Terlouw et al., 2016; O'Malley et al., 2018). While the respiratory changes are generally associated with aversion, there is no general agreement concerning the interpretation of the occurrence of convulsions or (involuntary) muscle contractions. The muscle contractions have been observed both before and after loss of consciousness (Forslid, 1987; Velarde et al., 2007; Verhoeven et al., 2016). However, assessment and interpretation of behavioral responses during the exposure CO_2 at high concentration under commercial conditions is in most situations not possible.

After CAS stunning, if the stunning is ineffective or if the animals recover consciousness, the welfare consequences are pain and fear, due to persistence of consciousness.

ABMs related to pain and fear after stunning are the signs of state of consciousness, which have to be checked through the three key stages of monitoring during the slaughter process: after stunning (between the end of stunning and hoisting), during sticking (cutting brachiocephalic trunk) and during bleeding. The assessment of the state of consciousness leads to two possible outcomes: outcomes of consciousness and outcomes of unconsciousness. In case outcomes of consciousness appears after stunning, appropriate back-up stunning method should be applied immediately to mitigate the welfare consequences.

ABMs related to the state of consciousness were selected in a previous opinion (EFSA AHAW Panel, 2013) and are described in full in the table below (Table 24).

Table 24: ABMs for assessment of 'State of consciousness' after Controlled atmosphere stunning method 1: CO_2 at high concentration

ABMs	Description
Breathing	Effective electrical stunning will result in immediate onset of apnoea (absence of breathing). Ineffectively stunned animals and those recovering consciousness will start to breathe in a pattern commonly referred to as rhythmic breathing, which may begin as regular gagging and involves respiratory cycle of inspiration and expiration. Rhythmic breathing can be recognised from the regular flank and/or mouth and nostrils movement. Recovery of breathing, if not visible through these movements, can be checked by holding a small mirror in front of the nostrils or mouth to look for the appearance of condensation due to expiration of moist air (EFSA AHAW Panel, 2013)
Palpebral and/or corneal reflex	The palpebral reflex is elicited by touching or tapping a finger on the inner/outer eye canthus or eyelashes. Correctly stunned animals will not show a palpebral reflex. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus The corneal reflex is elicited by touching or tapping the cornea. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus. Unconscious animals may also intermittently show a positive corneal reflex (EFSA AHAW Panel, 2013)
Response to nose prick or ear pinch	Response to a painful stimulus such as a pin prick to the muzzle (area between external nostrils) or the ear with a sharp instrument indicates consciousness following stunning (EFSA AHAW Panel, 2013)
Posture	Effective stunning will result in immediate collapse or loss of posture in animals. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse (EFSA AHAW Panel, 2013)
Vocalisations	Conscious animals may vocalise, and therefore purposeful vocalisation can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all conscious animals may vocalise (EFSA AHAW Panel, 2013)
Muscle tone	Loss of muscle tone can be recognised from the completely relaxed legs, floppy ears and tail and relaxed jaws with protruding tongue. Ineffectively stunned animals and those recovering consciousness will show a righting reflex and attempts to raise the head (EFSA AHAW Panel, 2013)

For controlled atmosphere stunning, EFSA AHAW Panel (2013) suggested the following flowchart (Figure 15), where ABMs to monitor the state of consciousness are suggested and included in toolboxes (see blue boxes in Figure 15), to be used at three key stages. For each key stage, three ABMs are suggested that are reliable in monitoring consciousness (above the dashed line), plus other two or three ABMs, that can be additionally used, which are less reliable (below the dashed line). For each ABM, corresponding outcomes of consciousness and unconsciousness are reported. In case outcomes of consciousness are observed in key stage 1 then an intervention should be applied (i.e. a backup method). After any reintervention, the monitoring of unconsciousness, according to the flowchart, should be performed again. Only when outcomes of unconsciousness are observed the process can continue to the next steps. Following key stage 3, in case outcomes of life are observed an intervention should be applied; only when outcomes of death are observed, the animals can be processed further.

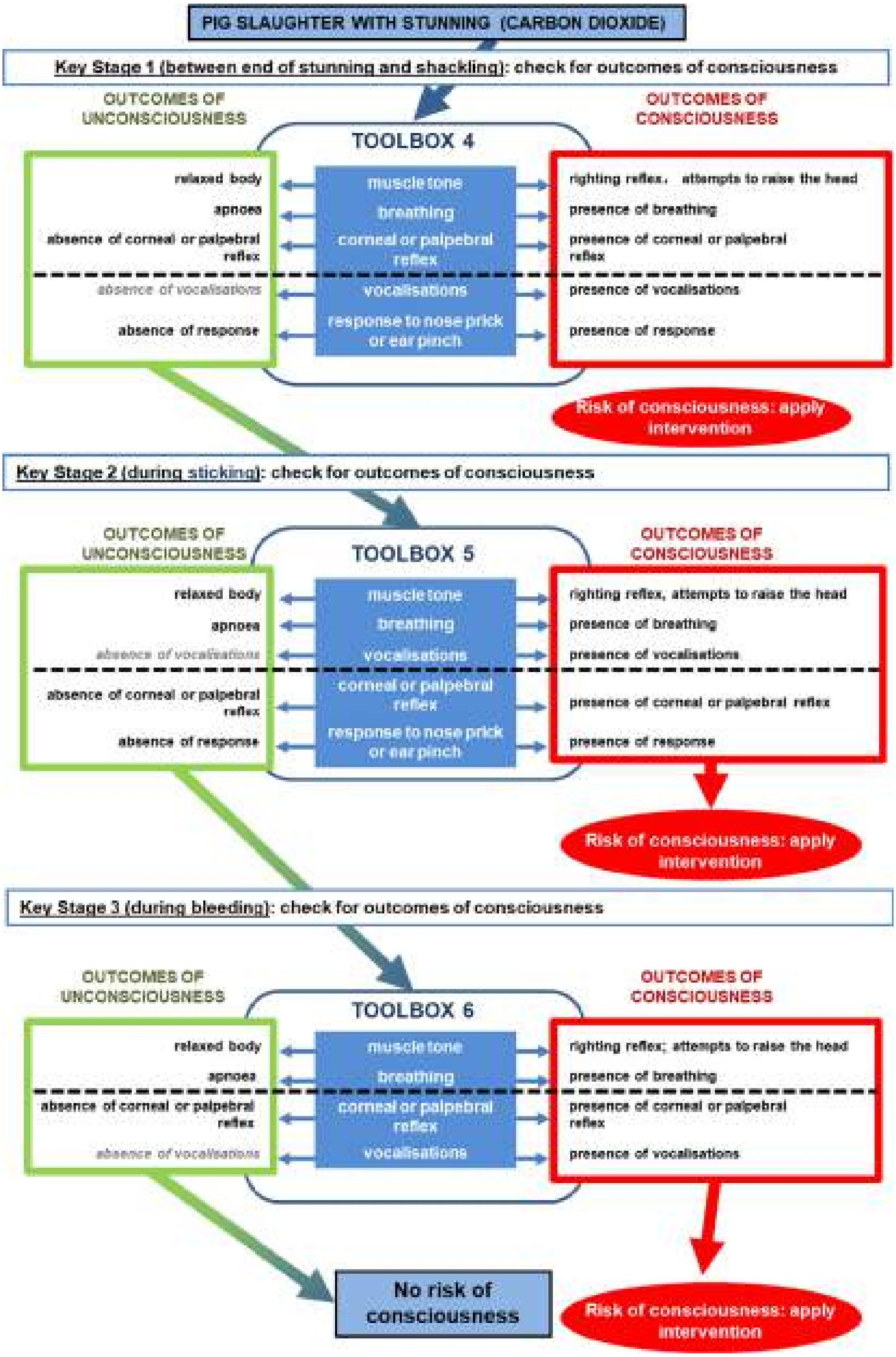

Figure 15: Flowchart of indicators for the monitoring of the state of consciousness of pigs during CO2 stunning (EFSA AHAW Panel, 2013)

3.2.4.3. Prevention and correction of welfare consequences and their related hazards

There are no preventive or corrective measures to the pain, fear and respiratory distress caused by the exposure to high CO_2 concentrations as this is inherent to the stunning method. The only way to prevent the hazard related to exposure to high CO_2 concentrations is to use other gas mixtures like inert gasses or mixtures of inert gases containing low CO_2 concentrations (see Chapter method 3; Mota-Rojas et al., 2012).

CO_2 should flow into the chamber or the location where animals are to be stunned and killed in a way that it does not create burns or excitement by freezing or lack of humidity. Moreover, the control of temperature and humidity of the gas mixture could improve the welfare of the animals. Inhalation of warm and humidified air helps them to alleviate physical discomfort and distress.

All animals should have enough space to lay down on the floor after loss of consciousness at the same time. Staff training can help to detect and prevent overloading of the equipment with pigs and to maintain adequate exposure time appropriate to gas concentration. Staff should also be trained to monitor signs of consciousness and to use adequate backup stunning methods for animals showing signs of consciousness at the exit of the gas stunner or during bleeding.

3.2.4.4. Outcome table on 'CO_2 at high concentration'

Table 25: Outcome table on 'CO_2 at high concentration'

Hazard (see Section 3.2.4.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Exposure to high CO_2 concentration	Pain, fear, respiratory distress	Equipment (Method)	The applied method requires exposure to high CO_2 concentration.	• None	None
Too short exposure time	Pain, fear, respiratory distress	Staff, equipment	Lack of skilled operators, lack of monitoring, line speed too high for the capacity of the slaughterhouse	• Staff training • Monitor and maintain adequate exposure time	Increase the exposure time to ensure adequate stunning
Too low concentration of gas	Respiratory distress	Staff, equipment	Lack of skilled operators, lack of gas monitoring, property of the gas, concentration of the gas, uneven distribution of the gas	• Staff training • Adequate gas monitoring and maintenance of required concentration • Maintenance and calibration of the equipment	increase gas concentration to ensure adequate stunning
Overloading	Pain, fear	Staff	Lack of skilled operators, high throughput rate	• Staff training • Do not exceed the recommended load of animals (they should lie together on the floor)	Stun using backup method
Too low temperature of the gas	Pain	Staff, Equipment	Lack of skilled operators, lack of monitoring of temperature of the gas Lack of proper vaporisation of the gas	• Staff training • Ensure that vaporisation functions properly	None

ABMs: high pitched vocalisations, escape attempts (pain, fear), reluctance to move, turning back and turning around (fear) gasping, hyperventilation and head shaking (respiratory distress), outcomes of consciousness (as a prerequisite for experiencing pain and fear).

3.2.5. Controlled atmosphere stunning method 2: Inert gases

Inert gases are considered direct or progressive exposure of conscious animals to an inert gas such as N2 (N_2) or Argon (Ar) with less than 2% by volume of residual oxygen in air leading to anoxia. Nowadays, exposure to inert gases is not used commercially and only data on experimental studies have been reported with exposure to N_2 or Ar. Inert gases will expand from liquid to gaseous form as soon as they are released from the pressurised containers, using heat from the environment. Therefore, the exposure of the animals to low temperature is not identified as a hazard.

Ar is heavier than air and could therefore be contained within a pit. On the other hand, the relative density of N_2 is slightly lower than air concentrations and cannot be sustained within a pit at a higher concentration than 94% by volume (Dalmau et al., 2010). In this situation, the residual oxygen (O_2) in N_2 will be 6% by volume and is not low enough to render the pigs unconscious.

Hypoxia occurring as a result of the inhalation of Ar or N_2 induces unconsciousness by depriving the brain of O_2. Cerebral dysfunction occurs when the partial pressure of oxygen in cerebral venous blood falls below 19 mmHg. The depletion of O_2 causes neuronal depolarisation and intracellular metabolic crisis leading to cellular death in neurons (Rosen and Morris, 1991; Huang et al., 1994). The mechanism of induction of unconsciousness by hypoxia is due to the inhibition of N-methyl-D-aspartate (NMDA) receptor channels in the brain, which is essential for maintaining neuronal arousal during conscious state (EFSA, 2004). In contrast to hypercapnia, the exposure to inert gases is non-aversive and does not cause sense of breathlessness during the induction of unconsciousness (see EFSA, 2004 for detail). However, other research indicated that hypoxia and hypercapnia have equal potency for air hunger (Moosavi et al., 2003). The time to induce unconsciousness when exposed to anoxia induced with Ar is shorter and less variable than when exposed to CO_2 at high concentration. For example, Raj et al. (1997) reported that the 95% lower and upper confidence limits for the time to abolition of somatosensory evoked potentials (SEPs) in the brain were 13s and 18s for Ar with less than 2% O_2, 15s and 18s for a mixture of 30% CO_2 and 70% Ar, and 17s and 25s for high concentration of CO_2 in air.

Exposure of pigs to 90% Ar in air resulted in lower signs of aversion than CO_2 at high concentration (AVMA, 2020). The method is considered a simple stunning method for pigs, if the duration of exposure is less than 7 min. Recovery of consciousness after exposure to inert gasses (EFSA, 2004) is very rapid and therefore sticking and bleeding must be applied swiftly.

The earliest sign of onset of unconsciousness and insensibility during exposure of pigs to inert gasses is the loss of posture (Raj et al., 1997). It may not always be possible to determine the exact time to loss of posture as pigs start to convulse prior or during the loss of posture. However, as exposure to the inert gases, these convulsions stop, leading to a complete loss of muscle tone. There is also a suppression of respiration, which can be evidenced from progressively declining rate and depth of breathing, resulting in complete cessation of any respiratory activity, including gagging at the exit of the chamber (Raj, 1999). Other signs of unconsciousness include fixed eyes, dilated pupil, absence of the palpebral (elicited by touching eyelashes or inner or outer canthus of the eye), corneal (elicited by touching the cornea) and pupillary (elicited by focusing bright light into the pupil) reflexes and absence of response to painful stimuli such as nose prick or ear pinch (Raj, 1999; Rodríguez et al., 2008).

Raj (1999) evaluated exposure of pigs to Ar with less than 2% residual O_2 under commercial slaughterhouse conditions. The time interval between end of exposure to Ar and sticking is critical which are reported in the table below (Table 26):

Table 26: The maximum recommended interval between end of exposure to Ar or a mixture of 30% CO_2 and Ar and sticking (Raj, 1999)

Exposure time in minutes	Maximum end of exposure to sticking interval in seconds
Three	25
Five	45
Seven	Not critical as pigs are killed

3.2.5.1. Hazard identification in the context of 'Controlled atmosphere stunning method 2: inert gases'

Hazards leading to 'Pain and fear:

The hazards identified during this process are:

1) Exposure to high O_2 concentrations
2) Too short exposure time
3) Overloading of the gondola.

These hazards can cause pain and fear and can lead to failure in onset of unconsciousness or to early recovery before or during bleeding.

Exposure to high O_2 concentration:

The residual O_2 concentration is higher than the required levels (e.g. > 2%) to render pigs unconscious within the applied time of exposure or to prevent recovery of consciousness during bleeding. High O_2 concentrations will prolong the induction of unconsciousness or animals may not be rendered unconscious (Raj and Gregory, 1996).

Exposure of pigs to high O_2 levels may not have any welfare consequences during exposure. It has been reported that induction of unconsciousness with anoxia is not aversive and recovery from anoxia-induced unconsciousness is not painful to pigs (Raj and Gregory, 1995, 1996 and EFSA, 2004). However, pigs will be exiting the stunner either inadequately stunned or fully conscious and they will be tipped out of the stunner causing pain and fear.

Too short exposure time:

When the duration of exposure is too short, animals will remain conscious or recover consciousness before or during bleeding.

Overloading of the gondola:

Exceeding the capacity of the equipment in terms of number of pigs that can be loaded into the gondola with available floor space leading to inadequate exposure to the gas in some pigs.

In a group stunning situation, overloading of the gondola may lead to animals falling on top of each other, and as a consequence, compression of the chest of animals at the bottom of the pile; these animals may not have adequate exposure to gas mixtures and hence suffer poor animal welfare outcomes (see Section 3.2.4.1).

3.2.5.2. Animal-based measures (ABMs) in the context of in the context of 'Controlled atmosphere stunning method 2: inert gases'

Pain and fear during exposure to inert gases can be assessed with the same ABMs that during exposure to CO_2 at high concentrations (see Section 3.2.4.2). The same signs of state of consciousness that are in the flowchart for CO_2 at high concentrations stunning were retrieved from the scientific literature and are therefore suggested also for 'inert gases' stunning method (see Table 24 for description of ABMS and flowchart in Section 3.2.4.2).

3.2.5.3. Prevention and correction of welfare consequences and their related hazards

Preventive measures include adequately monitor the O_2 concentration and exposure time to maintain the required concentration at the level of animals' heads and keep injecting inert gas until the required levels of O_2 are reached. The rate of induction, depth and duration of unconsciousness induced with inert gases depend on both exposure time and residual 0_2 concentration. Lower residual O_2 concentration (e.g. below 2%), requires shorter exposure times to induce an adequate level of unconsciousness than higher O_2 concentrations. This includes regular maintenance and calibration of gas monitoring equipment.

All animals should have enough space to lay down on the floor after loss of consciousness at the same time. Staff training can help to detect and prevent overloading of the equipment with pigs and to maintain adequate exposure time appropriate to gas concentration.

Staff should be trained to monitor signs of consciousness and to use adequate backup stunning methods for animals showing signs of consciousness at the exit of the gas stunner or during bleeding. See EFSA toolbox of indicators of consciousness (EFSA AHAW Panel, 2013) and to use adequate backup stunning methods for animals showing signs of consciousness at the exit of the gas stunner or during bleeding.

3.2.5.4. Outcome table on 'Inert gases'

Table 27: Outcome table on 'Inert gases'

Hazard (see Section 3.2.5.1)	**Welfare consequence/s occurring to the pigs due to the hazard**	**Hazard origin/s**	**Hazard origin specification**	**Preventive measure/s for the hazard (implementation of SOP)**	**Corrective measure/s for the hazard**
Exposure to high O_2 concentration	Pain, fear	Staff, equipment	Lack of skilled operators, lack of gas monitoring, property of the gas, concentration of the gas, uneven distribution of the gas	Adequate O_2 monitoring and maintenance of required concentration (below 2%) Maintenance and calibration of the equipmen	Increase concentration of the inert gas to ensure adequate stunning
Too short exposure time	Pain, fear	Staff, equipment	Lack of skilled operators, lack of monitoring, line speed too high for the capacity of the slaughterhouse	• Staff training • Monitor and maintain adequate exposure time	Increase the exposure time to ensure adequate stunning
Overloading	Pain, fear	Staff	Lack of skilled operators, high throughput rate	• Staff training • Do not exceed the recommended load of animals (they should lie together on the floor)	Stun using backup method

ABMs: high pitched vocalisations, escape attempts (pain, fear), reluctance to move, turning back and turning around (fear), outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.2.6. Controlled atmosphere stunning method 3: CO_2 associated with inert gases

CO_2 associated with inert gases is the direct or progressive exposure of conscious animals to a mixture of less than 40% CO_2 associated with inert gases, Ar or N2 with less than 2% residual oxygen (O_2) leading to hypercapnic anoxia.

Gas mixtures of Ar or N_2 and up to 30% CO_2 have high stability and uniform concentrations along the pit. However, the higher the concentration of N2 in the gas mixture with CO_2, the lower the relative density of the mixture and, therefore, the more difficult it is to displace the oxygen from the pit (Dalmau et al., 2010).

From the results in experiments with pigs exposed to different N2/CO_2 mixtures ranging from containing 15–30% CO_2 compared to 90% CO_2, Llonch et al. in 2012 concluded that the N_2 / CO_2 stunning methods exhibit fewer signs of aversion and breathlessness than in 90% CO_2. Taking into account the time to enter the crate and the percentage of animals entering voluntarily, Llonch et al. concluded that exposure to 70% N_2/30% CO_2, 80%N_2/20%CO_2 and 85%N_2/15%CO_2 mixtures does not represent a negative stimulus that animals try to avoid in consecutive sessions. However, based on the percentage of animals showing retreat and escape attempts, gasping and vocalisations before the loss of balance, the same authors concluded that the exposure to those gas mixtures is more aversive than exposure to atmospheric air. Pigs show a similar aversion to the three gas mixtures although a higher CO_2 concentration in the atmosphere causes an increase of the sense of breathlessness. Pigs exposed to 80% N_2/20% CO_2 show less muscular excitation during exposure to the gas. The results of another study by Llonch et al. indicated that pigs show signs of aversion to the inhalation of 15–30% CO_2 in N_2 atmosphere compared to atmospheric air but the aversion response did not increase in consecutive sessions (Llonch et al., 2012a,b).

Raj and Gregory (1996) reported that the addition of up to 30% CO_2 to an anoxic atmosphere reduces the time needed to induce unconsciousness with minimal aversion. However, according to Raj and Gregory (1995), the CO_2 concentration of the gas mixture should be below 30% in the atmosphere in order to avoid aversion. The time to loss of consciousness occurring during exposure of animals to gas mixture depends upon the composition of the gas mixtures.

Loss of consciousness determined by the loss of posture is similar among the gas mixtures of N_2 and containing 30–15% CO_2. However, the duration of unconsciousness is reduced with N_2 gas mixtures with up to 30% CO_2 compared to 90% CO_2 when the same time of exposure is applied (Llonch et al., 2012c).

The exposure of pigs to either Ar induced anoxia or the CO_2/ Ar mixture for 3 min resulted in satisfactory stunning. However, bleeding should commence within 15 s to avoid resumption of consciousness, as in head only electrical stunning. A 5-min exposure to these gas mixtures followed by bleeding within 45 s prevented carcass convulsions during bleeding. The exposure of pigs to Ar-induced anoxia or the CO_2–Ar mixture for 7 min resulted in death in most of the pigs.

While using a mixture of CO_2 and inert gases, the concentration of CO_2 as well as the residual oxygen are critical, and the duration of exposure required to stun pigs will vary depending upon the concentrations of these gases.

Nevertheless, Raj (1999) evaluated exposure of pigs to a mixture containing 30% CO_2 in Ar with 2% residual O_2 under commercial slaughterhouse conditions. The time interval between end of exposure to this alternative gas mixtures and sticking is critical which are reported in Table 26 (see Section 3.2.5)

The earliest sign of onset of unconsciousness and insensibility during exposure of pigs to gas mixtures is the loss of posture (Verhoeven et al., 2015). Field observations of gas stunning suggest that it may not always be possible to determine the exact time to loss of posture as pigs start to convulse prior to loss of posture (frequently described as the excitation phase). However, as exposure to a gas mixture continues, these convulsions stop, leading to a complete loss of muscle tone. There is also a suppression of respiration, which can be evidenced from progressively declining rate and depth of breathing, resulting in complete cessation of any respiratory activity, including gagging at the exit of the chamber (Raj, 1999). Other signs of unconsciousness induced by exposure to high concentrations of CO_2 include fixed eyes, dilated pupils, absence of the palpebral (elicited by touching eyelashes or inner or outer canthus of the eye), corneal (elicited by touching the cornea) and pupillary (elicited by focusing bright light into the pupil) reflexes and absence of response to painful stimuli such as nose prick or ear pinch (Raj, 1999; Rodríguez et al., 2008).

3.2.6.1. Hazard identification in the context of 'Controlled atmosphere stunning method 3: CO2 associated with inert gases'

Hazards leading to 'Pain, fear and respiratory distress':

The hazards identified during this process are:

1) Exposure to high CO_2 concentrations
2) Too short exposure time
3) Too low temperature of the gas
4) Overloading of the gondola.

These hazards can cause pain, fear and respiratory distress and can lead to failure in onset of unconsciousness or to early recovery before or during bleeding.

Exposure to high CO_2 concentrations:

From the results in experiments with pigs exposed to different N2/ CO_2 mixtures ranging from containing 30–15% CO_2 compared to 90% CO_2 Llonch et al. (2012b) concluded that the N_2/CO_2 stunning methods exhibit lower aversion and respiratory distress than in 90% CO_2. However, the onset of unconsciousness is even slower and the signs of recovery appear earlier than with CO_2 at high concentration.

Mota-Rojas et al. (2012) reviewed the physiological effects of exposure of pigs to high concentrations of CO2 and concluded that the use of 90% by volume of Ar in air or a mixture of low concentration of CO_2 in Ar is a better alternative to high concentrations of CO2 on animal welfare grounds.

Too short exposure time:

During exposure to gas mixtures, loss of consciousness is not immediate and the induction of unconsciousness and depth of unconsciousness depends on the gas concentration as well as on the duration of exposure. When the duration of exposure is too short, animals will remain conscious or recover consciousness before or during bleeding.

Too low temperature of the gas:

Administration of liquid or solid CO_2 into the chamber due to the lack of vapourisation will drop the environmental temperature, which can cause pain to the pigs. Liquid CO_2 needs an external heat source to vapourise to the ambient temperature.

Overloading of the gondola:

Exceeding the capacity of the equipment in terms of number of pigs that can be loaded into the gondola with available floor space leading to inadequate exposure to the gas in some pigs.

In a group stunning situation, overloading of the gondola may lead to animals falling on top of each other, and as a consequence, compression of the chest of animals at the bottom of the pile; these animals may not have adequate exposure to gas mixtures and hence suffer poor animal welfare outcomes.

3.2.6.2. Animal-based measures (ABMs) in the context of in the context of 'Controlled atmosphere stunning method 3: CO_2 associated with inert gases'

Pain, fear and respiratory distress during exposure to inert gases can be assessed with the same ABMs that during exposure to CO_2 at high concentrations (see Section 3.2.4.2). The same signs of consciousness that are in the flowchart for CO_2 at high concentrations stunning were retrieved from the scientific literature and are therefore suggested also for 'CO_2 associated with inert gases' stunning method (see Table 24 for description of ABMS and flowchart in Section 3.2.4.2).

3.2.6.3. Prevention and correction of welfare consequences and their related hazards

Preventive measures include adequately monitor the CO_2 and O_2 concentrations and exposure time to maintain the required concentrations at the level of animals' heads and keep injecting the gases until the required levels of CO_2 and O_2 are reached. The rate of induction, depth and duration of unconsciousness induced with gas mixtures depend on both exposure time and gas concentration. Higher concentrations of CO_2 require shorter exposure times to induce an adequate level of unconsciousness than lower CO_2 concentrations. Furthermore, gas monitoring equipment should be routinely maintained and calibrated.

All animals should have enough space to lay down on the floor after loss of consciousness at the same time. Staff training can help to detect and prevent overloading of the equipment with pigs and to maintain adequate exposure time appropriate to gas concentration.

Staff should be trained to monitor signs of consciousness. See EFSA toolbox of indicators of consciousness (EFSA AHAW Panel, 2013) and to use adequate backup stunning methods for animals showing signs of consciousness at the exit of the gas stunner or during bleeding.

3.2.6.4. Outcome table on 'CO_2 associated with inert gases'

Table 28: Outcome table on 'CO_2 associated with inert gases'

Hazard	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Exposure to high CO_2 concentration	Pain, fear, respiratory distress	Equipment (Method)	Too high CO_2 concentration in the gas mixture	• Reduce to minimum the CO_2 concentration • Replace the CO_2 with inert gases	None
Too short exposure time	Pain, fear, respiratory distress	Staff, equipment	Lack of skilled operators, lack of monitoring, line speed too high for the capacity of the slaughterhouse	• Staff training • Monitor and maintain adequate exposure time	Increase the exposure time to ensure adequate stunning
Exposure to high O_2 concentration	Pain, fear	Staff, equipment	Lack of skilled operators, lack in gas monitoring, concentration of the gas, uneven distribution of the gas	• Adequate O_2 monitoring and maintenance of required concentration (below 2%) • Maintenance and calibration of the equipment	Reduce below 2% O_2
Overloading	Pain, fear	Staff	Lack of skilled operators, high throughput rate	• Staff training • Do not exceed the recommended load of animals (they should lie together on the floor)	Stun using backup method
Too low temperature of the gas	Pain	Staff, Equipment	Lack of skilled operators, lack of monitoring of temperature of the gas Lack of proper vapourisation of the gas	• Staff training • Ensure that vapourisation functions properly	None

ABMs: escape attempts, high pitched vocalisations (pain, fear), reluctance to move, turning back and turning around (fear), gasping, hyperventilation and head shaking (respiratory distress), outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.2.7. Penetrative captive bolt stunning

Restraint of pigs and immobilisation and presentation of the head improves accuracy of captive bolt stunning (Figure 16). Individual pigs can be restrained by passing a rope noose around the upper jaw, behind the canine teeth: when the pig pulls back it will be in the position to be immediately stunned (HSA, 2016b). Boards can be used to restrict the movement of pigs. Restraining conveyors can also be used, where needed (HSA, 2016a). Penetrative captive bolt normally powered by cartridge is mainly used as backup or emergency method in some slaughterhouses. The guns are designed to fire a retractable steel bolt that penetrates the cranium and enters the brain. The impact of the bolt on the skull results in brain concussion (EFSA, 2004) and immediate loss of consciousness. Afterwards, the unconsciousness is prolonged by the structural damage to the brain, which results in marked subarachnoid and intraventricular hemorrhages, especially adjacent to the entry wound and at the base of the brain. It causes subsequent disruption of the brain tissue and helps to prolong the duration of unconsciousness and insensibility. The animals may not die immediately depending on the degree of injury to the brain (Lambooij and Algers, 2016; Raj and Velarde, 2016). Therefore, captive bolt stunning shall be followed as quickly as possible by bleeding or destruction of the brain and upper spinal cord by pithing if bleeding cannot be carried out immediately after the shot (e.g. emergency slaughter in the lorry).

According to the Humane Slaughter Association (HSA, 2016b), pigs are among the most difficult animals to shoot with a penetrative captive bolt. There are two reasons for this: first, the target area is very small and this problem can be exacerbated by the 'dish' (concave) face shape of certain breeds and in aged pigs; second, the brain lies quite deep in the head, relative to other species, with a mass of sinuses lying between the frontal bone and the brain cavity.

To achieve successful stunning, the captive bolt device must be correctly placed, and a bolt of adequate length and diameter must be used. Captive bolt should be pointed perpendicular to the parietal bones of pigs. The ideal shooting position is in the midline of the forehead, 1 and 2 cm above eye level, and the muzzle of the captive bolt should be placed against the head and directed towards the tail (EFSA, 2004). Boars and large sows may have a ridge of bone running down the centre of the forehead. This may interfere or prevent the bolt penetrating the brain cavity and the pig will not be stunned effectively. In such cases, the recommended shooting position is 3–4 cm above the eye level and the muzzle of the captive bolt should be placed slightly to one side of the ridge, aiming into the centre of the head (HSA, 2016b). However, large boars are more difficult to stun using this method as the sinuses in the forehead are well developed and the brain is laying deeper in the head than in other pigs and are preferably killed by use of a free-bullet firearm (Blackmore, 1995; HSA, 2016d).

Figure 16: Restraint and application of captive bolt stunning (Source: IRTA)

The bolt diameter and the strength, velocity and penetration depth of the gun are important parameters to ensure efficacy of the stun. It is recommended that the most powerful cartridge available is used. The cartridges typically used are of two to three grains (130–190 mg) of smokeless powder but can be used up to 7 grains (450 mg) in the case of adult pigs. It is important, however, to refer to the manufacturers' instructions so that the correct cartridges are used for each model of stunner; they are identified by calibre (0.22 or 0.25), color and headstamp.

Successful induction of brain concussion manifests as immediate collapse of the animal and onset of apnea (absence of breathing), followed by the onset of a tonic seizure, which can be recognised by its head extended, hind legs rigidly flexed under the body and fixed eyes. The forelegs may be flexed initially and then gradually straightened out. This period last for 10–20 s and is followed by a period of clonic convulsion with kicking movement. Ineffective or unsuccessful captive bolt stunning can be recognised by the failure to collapse, the presence of breathing (including labored breathing) and the absence of tonic and clonic seizures; in some cases, animals may also vocalise (HSA, 2016b).

3.2.7.1. Hazard identification in the context of 'Penetrative captive bolt stunning'

During the restraining, the welfare consequences are pain and fear. After the captive bolt application, if the stunning is ineffective, the welfare consequences are pain and fear due to consciousness.

Hazards leading to 'Pain and fear':

The hazards identified during this process are:

1) Restraint
2) Incorrect position and direction of the shot
3) Incorrect captive bolt parameters

These hazards can lead to the welfare consequence of pain and fear and can lead to failure in onset of unconsciousness or to early recovery before or during bleeding.

<u>Restraint</u>

Individual pig and its head need to be immobilised to present its head to the operator for the purpose of correct position and direction of the shot. Manual restraining methods such as nose snare may carry the risk of pain to the pigs (HSA, 2016a).

<u>Incorrect position and direction of the shot</u>

Firing a captive bolt away from the recommended shooting position leads to ineffective stunning and pain due to the impact of the bolt on the skull. Captive bolt guns can be either trigger or contact fired. With contact fired guns, there is no possibility to correct the position of the gun once it touches the head of the animal. Incorrect position can be due to the lack of skilled operators or fatigue, poor restraint and wrong target area or angle of shooting. Inappropriate placement and direction can be also consequence of the 'dish' (concave) face shape of the forehead of certain breeds and in aged pigs.

<u>Incorrect captive bolt parameters</u>

The extent of the damage and stunning effectiveness depends also on the bolt length and diameter and velocity of the impact. Incorrect bolt parameters may render the pigs ineffectively stunned. It may be caused by e.g. low cartridge power, low bolt velocity, shallow penetration and faulty equipment (too narrow bolt diameter). If the bolt is too narrow, or the velocity is too low, there will not be enough energy transfer to the head to induce effective stunning (EFSA, 2004). The cartridge used should be those recommended for the equipment by the manufacturer (HSA, 2016b).

3.2.7.2. Animal-based measures (ABMs) in the context of in the context of 'Penetrative captive bolt stunning'

During the restraining, the welfare consequences are pain and fear. After stunning, if the stunning is ineffective or if the animals recover consciousness, the welfare consequences are pain and fear due to persistence of consciousness. Therefore, consciousness is not a welfare consequence per se but a prerequisite for experiencing pain and fear.

ABMs related to pain and fear during restraint and loading into the restraining device are high pitched vocalisations, escape attempts, injuries, reluctance to move and turning back (see details in Table 19, Section 3.2.1.1).

ABMs related to pain and fear after stunning are the signs of state of consciousness, which have to be checked through the three key stages of monitoring during the slaughter process: after stunning (between the end of stunning and hoisting), during sticking (cutting brachiocephalic trunk) and during bleeding. The assessment of the state of consciousness leads to two possible outcomes: outcomes of consciousness and outcomes of unconsciousness.

In case outcomes of consciousness appears after stunning, appropriate back-up stunning method should be applied immediately to mitigate the welfare consequences.

As retrieved from literature, the recommended ABMs for monitoring after stunning are posture, breathing, tonic/clonic seizure, corneal or palpebral reflex, vocalisation and eyes movements. For monitoring at sticking, the recommended ABMs to be used are body movements, breathing, eye movements, corneal or palpebral reflex and spontaneous blinking. For monitoring during bleeding, the recommended ABMs are: muscle tone, breathing corneal or palpebral reflex, vocalisation and spontaneous blinking. A description of these ABMs is given in the table below (Table 29).

Table 29: ABMs for assessment of 'State of consciousness' after penetrative captive bolt stunning

ABMs	Description
Tonic/clonic seizures	Effective stunning leads to the onset of tonic–clonic seizures soon after immediate collapse of the animal. The tonic seizure, which may be recognised from the tetanus, lasts for several seconds and is followed by clonic seizures lasting for seconds and leading to loss of muscle tone (EFSA AHAW Panel, 2013)
Breathing	Effective stunning will result in immediate onset of apnoea (absence of breathing). Ineffectively stunned animals and those recovering consciousness will start to breathe in a pattern commonly referred to as rhythmic breathing, which may begin as regular gagging and involves respiratory cycle of inspiration and expiration. Rhythmic breathing can be recognised from the regular flank and/or mouth and nostrils movement. Recovery of breathing, if not visible through these movements, can be checked by holding a small mirror in front of the nostrils or mouth to look for the appearance of condensation due to expiration of moist air (EFSA AHAW Panel, 2013)
Palpebral and/or corneal reflex	The palpebral reflex is elicited by touching or tapping a finger on the inner/outer eye canthus or eyelashes. Correctly stunned animals will not show a palpebral reflex. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus.The corneal reflex is elicited by touching or tapping the cornea. Ineffectively stunnedanimals and those recovering consciousness will blink in response to the stimulus. Unconscious animals may also intermittently show a positive corneal reflex (EFSA AHAW Panel, 2013)
Spontaneous blinking	Conscious animals may show spontaneous blinking and therefore this sign can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all the conscious animals may show spontaneous blinking (EFSA AHAW Panel, 2013)
Posture	Effective stunning will result in immediate collapse or loss of posture in animals that are not restrained or prevented from doing so. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse (EFSA AHAW Panel, 2013)
Vocalisations	Conscious animals may vocalise, and therefore purposeful vocalisation can be used torecognise ineffective stunning or recovery of consciousness after stunning. However, not all conscious animals may vocalise (EFSA AHAW Panel, 2013)
Muscle tone	Stunned animals will show general loss of muscle tone after the termination of tonic–clonic seizures coinciding with the recovery of breathing and the corneal reflex if not previously stuck. Loss of muscle tone can be recognised from the completely relaxed legs, floppy ears and tail and relaxed jaws with protruding tongue. Ineffectively stunned animals and those recovering consciousness will show a righting reflex and attempts to raise the head (EFSA AHAW Panel, 2013)
Eye movements	Eye movements and the position of the eyeball can be recognised from closeexamination of eyes after stunning. Correctly stunned animals will show fixed eyes, and this can be recognised from wide open and glassy eyes with clearly visible iris/cornea in the middle. Eyeballs may be obscured in some animals owing to rotation into the eye socket following effective stunning. Ineffectively stunned animals and those recovering consciousness will show eye movements (EFSA AHAW Panel, 2013)
Body movement	Body movements in response to sticking include intentional or purposeful kicking and body or head movements that may occur as a nociceptive response to incision of the skin for the purpose of bleeding and/or insertion of the knife for the purpose of sticking Therefore, the indicator body movements for checking for the state of consciousness is applicable only to key stage 2. The difficulty with the indicator is that some unconscious animals can react to sticking, and this mainly takes the form of movement of the forelegs, which is referred to in the scientific literature as the somatic reflex arc and such reflexes do not involve the central nervous system. Nevertheless, when such a reflex is seen during sticking, 'personnel' should check for other signs to rule out persistence of consciousness (EFSA AHAW Panel, 2013)

These ABMs were therefore included in the following flowchart for penetrative captive bolt stunning (Figure 17), including toolboxes of ABMs to be used at three key stages to monitor the state of consciousness. It is to be noted that these ABMs are not selected based on sensitivity and specificity, and therefore, they are not ranked in order of reliability. For each ABM, corresponding outcomes of consciousness and unconsciousness are reported. In case outcomes of consciousness are observed in key stage 1 then an intervention should be applied (i.e. a backup method). After any reintervention, the monitoring of unconsciousness, according to the flowchart, should be performed again. Only when outcomes of unconsciousness are observed the process can continue to the next steps. Following key stage 3, in case outcomes of life are observed an intervention should be applied; only when outcomes of death are observed the animals can be processed further.

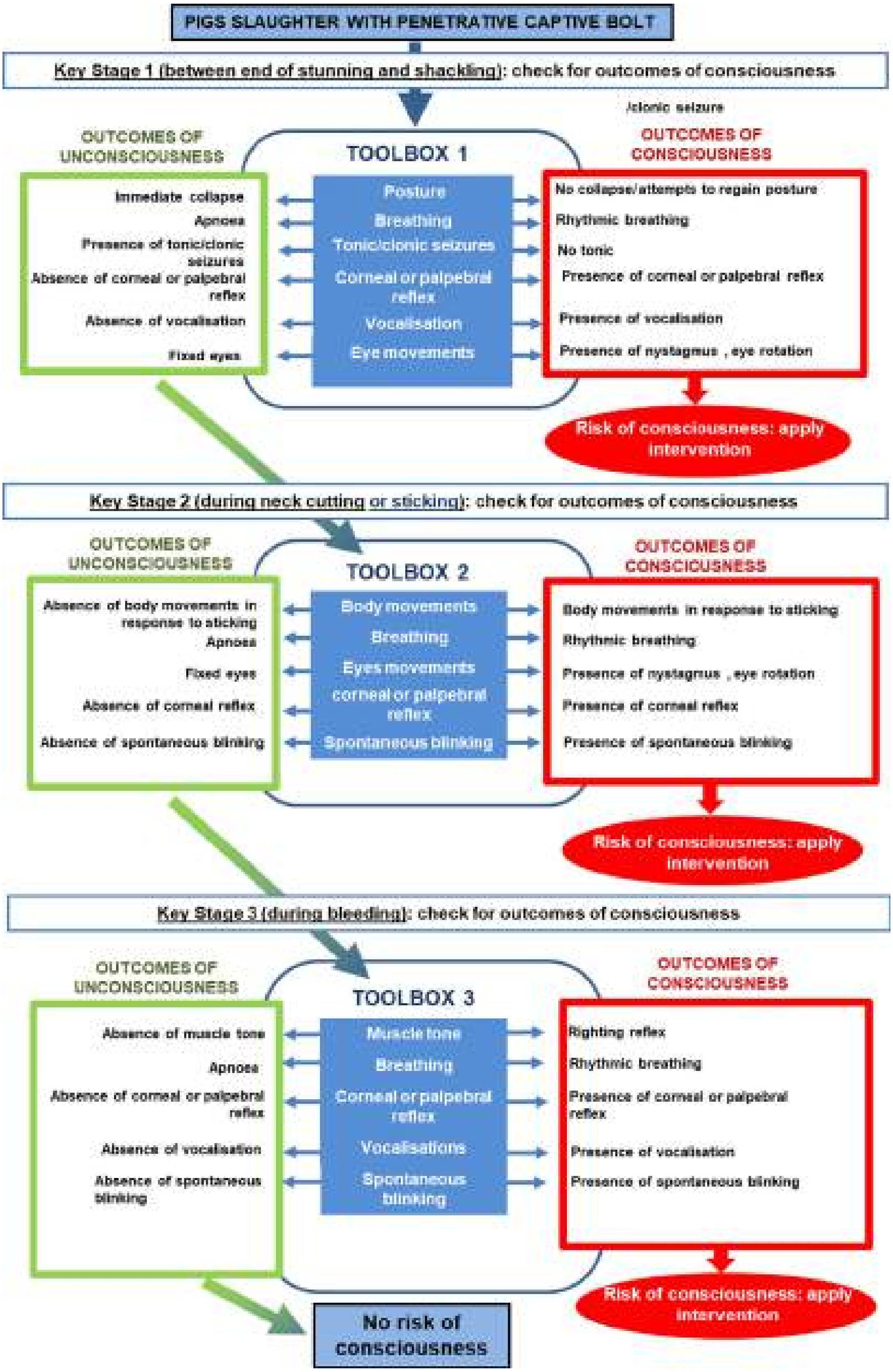

Figure 17: Flowchart for penetrative captive bolt stunning, including indicators to be used for monitoring the state of consciousness

3.2.7.3. Prevention and correction of welfare consequences and their related hazards

Pain and fear during the restraining and application of the penetrative captive bolt stunning can be prevented through adequate design and maintenance of the restraining and stunning equipment and staff competence and training.

The restraint should suit the size of the animal. In the case of manual restraint, gentle handling of the pigs while they are restrained can minimise fear. Owing to this, duration of restraint should be as short as possible and, as a guide of good practice, animals should not be restrained until the operator (s) is ready to stun and bleed them. Careful selection of people with adequate skills and the right attitude or giving training for them to acquire the skills appropriate to the tasks and species of pigs would help to minimise fear and pain in the animals being handled. Staff training and rotation, use of an appropriate restraint, proper placement and firing of the gun, equipment fit for the purpose and regular cleaning and maintenance of equipment according to manufacturer's instructions are preventive measures.

After an ineffective shot, the mitigation measures are address to re-stun as soon as possible in the correct position and direction, and with the correct parameters or with an alternative backup method.

3.2.7.4. Outcome table on 'Penetrative captive bolt stunning'

Table 30: Outcome table on 'Penetrative captive bolt stunning'

Hazard (see Section 3.2.7.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Restraint	Pain, fear	Staff, equipment	Immobilisation of the animal and presentation of the head of the pig to the operator are required	• None	Keep the duration of restrain to the minimum
Incorrect position and direction of the shot.	Pain, fear	Staff	Lack of skilled operators, operator fatigue, poor restraint, wrong target area or angle of shooting, inappropriate placement of the gun due to the shape of the head	• Staff training and rotation, appropriate restraint of the pig, proper placement of the gun	Stun in the correct position and with the correct direction
Incorrect captive bolt parameters	Pain, fear	Staff, equipment	Lack of skilled operators, wrong choice of equipment, inappropriate cartridge and power, poor maintenance of the equipment, too narrow bolt diameter, shallow penetration, low bolt velocity.	• Staff training, appropriate restraint of the pigs, ensuring equipment is fit for the purpose, regular maintenance of equipment	Stun with correct parameters or apply backup method

ABMs: escape attempt, high pitched vocalisations, outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.2.8. Percussive blow to the head stunning

Percussive blow to the head is commonly used as an on-farm killing method in neonatal piglets (≤ 5 kg live weight) but might be used also for slaughter as backup or emergency stunning method.

This method is mainly performed by holding piglets by the body, placing its head on a hard surface and delivering a blow to the forehead with a hard object (e. g. metal pipe, bat or solid wooden stick) with sufficient force and accuracy to lead to brain concussion. It can also be performed by holding the piglets with both hands around its hindlegs and swinging the piglet's head towards a hard surface. In both procedures, it is essential that the blow is delivered swiftly, firmly and with absolute determination (HSA, 2016c) to provoke severe damage to the brain and the immediate unconsciousness. The percussive blow is not always effective in producing death and should be immediately followed by bleeding.

Successful induction of brain concussion manifests as immediate collapse of the animal and onset of apnoea (absence of breathing), and onset of a tonic seizure, which can be recognised by its head extended, hind legs rigidly flexed under the body and fixed eyes. Afterwards, clonic convulsions of variable intensity are expected result of an effective stun (Grist et al., 2018a). Ineffective or unsuccessful percussive blow to the head can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and in extreme cases, animals may also vocalise.

To be effective it must involve a single blow to the correct position on the cranium of sufficient force to produce immediate depression and severe damage of the brain. If insufficient kinetic energy is delivered to the cranium, there is the potential for incomplete concussion, leading to pain and fear. To ensure death, manual blunt force trauma shall be followed as quickly as possible by bleeding procedure, either by cutting the throat from ear to ear to sever both carotid arteries and both jugular veins or by inserting the knife into the base of the neck towards the entrance of the chest to sever all the major blood vessels where they emerge from the heart (HSA, 2016c).

The manual delivering of a blow to the forehead with a hard object or hitting the head towards a hard surface are entirely manual processes and prone to error. It requires a level of skill that most stockpersons and veterinarians would be unlikely possess if they infrequently perform the procedure. Consequently, the probability of achieving an immediate and humane kill in all cases is low (Grist et al., 2017). It is less reproducible between animals, and there is significant risk of causing incomplete concussion. Percussive blow might be used only when no other stunning method is available.

As an alternative to manual blunt force trauma, mechanical blunt force trauma using a non-penetrating captive bolt has been demonstrated as a viable method of producing an immediate stun followed by death in neonate piglets (Grist et al., 2017, 2018a,b). Pneumatic non-penetrating captive bolt gun powered to deliver a kinetic energy of 27.7 J (120 psi) provides immediate and irreversible loss of consciousness and brain death in piglets up to 10.9 kg with a single application on the frontal–parietal position (Grist et al., 2017, 2018a). The body of the piglet is restrained with one hand and the head should be rest on a hard surface (Figure 18). The efficacy of this method relies on the head being firmly restrained on a hard surface. The use of a non-penetrating captive bolt with a 1-grain cartridge also results in death in neonate piglets (up to 5 kg) when applied on the midline on the frontal/parietal bone (Grist et al., 2018b). The average kinetic energy produced on impact by this device is 47 Joules.

Figure 18: Application position for percussive blow to the head stunning of a piglet (Grist et al., 2018a)

3.2.8.1. Hazard identification in the context of 'Percussive blow to the head'

Hazards leading to 'Pain and fear':

The hazards identified during this process are:

1) Manual restraint
2) Inversion
3) Incorrect application of blow or shot to the head
4) Insufficient force.

The hazards identified during stunning with 'percussive blow', relevant welfare consequences and related ABMs, origin of hazards, preventive and corrective measures are reported in the Outcome table, in Section 3.2.8.4.

Manual restraint

The delivery of a blow to the forehead with either a non-penetrating captive bolt or a hard object requires the immobilisation of the piglets and the head. Manual restraining of the piglets may carry the risk of fear and pain.

Inversion

Manual blunt force trauma might be performed by holding the piglets in an upside-down position and swinging the piglet's head towards a hard surface. This position and movement will cause fear and pain. Inversion can cause pain and fear directly or because of the incorrect application of the blow, which can lead to failure in onset of unconsciousness.

Incorrect application of blow or shot to the head

If piglets are hit in the wrong place, the blow to the head will cause severe pain. Lack of skilled operators, operator fatigue and poor restraint, wrong choice of the tool to deliver the blow can lead to incorrect application of blow to the head.

Insufficient force

When the kinetic energy (velocity and bolt mass) of the impact to the cranium fails to cause immediate brain concussion. In non-penetrating captive bolt, it might occur when the bolt energy is below 27.2 J.

3.2.8.2. Animal-based measures (ABMs) in the context of in the context of 'Percussive blow to the head'

ABMs related to pain and fear during restrain are high-pitched vocalisations, escape attempts, injuries, reluctance to move and turning back (see details in Table 19, Section 3.2.1.1)

ABMs related to pain and fear after stunning are the signs of state of consciousness. The same signs of consciousness that are suggested for penetrative bolt stunning were retrieved from the literature and therefore are suggested here for percussive blow to the head stunning method (see Table 29 for description of ABMs of state of consciousness and flowchart in Section 3.2.7.2).

3.2.8.3. Prevention and correction of welfare consequences and their related hazards

There are no preventive or corrective measures to the pain and fear caused by manual restraint and inversion as this part of the stunning method. Therefore, it is preferable to choose a different method.

Non-penetrating captive bolt device has the advantage of reproducibility, less reliance upon operator ability in comparison with manually delivered blow to the head.

Recommended measures to prevent the incorrect application of blow to the head are staff training and rotation, use of appropriate tool and delivery of accurate blow and adequate.

Training of staff to use of adequate procedures to monitor (un)consciousness will benefit to prevent and correct stunning failures.

Inadequate stunning should be corrected by application of an adequate back-up procedure.

3.2.8.4. Outcome table on 'Percussive blow to the head (up to 5 kg)'

Table 31: Outcome table on 'Percussive blow to the head (up to 5 kg)'

Hazard (see Section 3.2.8.1)	Welfare consequence/s occurring to the piglets due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Manual restraint	Pain, fear	Staff	Immobilisation of the animal and presentation of the head of the piglet to the method are required	• Train staff to keep it as short as possible	None
Inversion	Pain, fear	Staff	Manually inverting pigs for the application of the blow	• Avoid inversion of conscious animals	None
Incorrect application	Pain, fear	Staff, equipment	Lack of skilled operators, operator fatigue, poor restraint, hitting in wrong place, insufficient force delivered to the head, wrong choice of tool to deliver the blow	• Staff training and rotation • Delivery of the blow with accuracy and adequate force. • Use appropriate tool	Correct application of the method
Insufficient force	Pain, fear	Staff, equipment	Lack of skilled operators, wrong choice of equipment, inappropriate cartridge and power, low bolt velocity, poor maintenance of the equipment.	• Staff training • ensuring equipment is fit for the purpose • regular maintenance of equipment	Stun with correct energy or apply backup method

ABMs: high pitched vocalisations, escape attempts (pain, fear), outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.2.9. Firearm with free projectile

Firearm with free projectile is considered a killing method as one or more projectiles are fired into the cranium causing immediate unconsciousness and extensive damage and destruction of the brain, preventing any possibility of recovery and the consequent death.

Pigs are generally shot at close range with handguns (< 10 cm) or shotguns (at a distance between 5 and 25 cm). When used properly, this method is quick and requires minimal or no restraint of the animal (HSA, 2016d). The method might be advantageous in situations involving pigs which cannot be easily gathered or restrained (HSA, 2016d).

To ensure effective stunning and killing, it is recommended that animals are shot on the frontal region of the head, in the same position as for captive bolt, aiming to penetrate the skull and maximise damage to the structures of the brainstem (midbrain, pons and medulla). In addition to the position and angulation of the shot, the projectile must have sufficient kinetic energy to ensure penetration of the skull to a level beyond the brain stem and sufficient damage to the brain, brain stem and upper spinal cord to produce concussion and instantaneous death. The ideal ammunition is one which expands upon impact and dissipates its energy within the brain cavity (HSA, 2016d), causing destruction of the mid-brain and brain stem.

According to the HSA (2016d), the ammunition for a handgun should have a minimum calibre of .32 inches, generate a minimum muzzle energy of at least 200J and be round-nose, lead bullets to facilitate penetration and distortion. Boars and sows may require a 0.30 calibre bullet when using a riffle.

Older pigs and exotic breeds, such as the Vietnamese Pot Bellied Pig, often have foreheads of thick bone and this can cause problems when using free bullet (HSA, 2016d).

Effective concussion and destruction of the brain manifests as immediate collapse and onset of apnoea (absence of breathing). Some animals might show severe tonic activity and others completely relaxed muscles (HSA, 2016d). This period might be followed by a period of clonic convulsion with kicking movement. During this period, pigs do not show corneal reflex nor blinking. Ineffective or unsuccessful application can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and the absence of tonic and clonic seizure; in extreme cases, animals may also vocalise.

The use of firearms in enclosed spaces, or when animals are on hard surfaces, could result in ricochet of free bullets and is to be avoided for health and safety reasons. The operators and bystanders must use extreme care in positioning of themselves and others when the procedure is performed. Another disadvantage is that in cases involving fractious animals, it may be difficult to get close enough to accurately hit the vital target area.

3.2.9.1. Hazard identification in the context of 'Firearm with free projectile'

The hazards identified during this process, which can cause consciousness leading to pain and fear, are:

1) Incorrect position of the shot
2) Inappropriate power and calibre of the cartridge
3) Inappropriate type of projectile.

The hazards identified related to the 'firearm with free projectile', relevant welfare consequences and related ABMs, origin of hazards, preventive and corrective measures are reported in Table 32.

<u>Incorrect position and direction of the shot</u>

Like with captive bolt, pigs can be difficult to kill with free bullet due to the anatomy of the skull and frontal sinus. Shooting away from the recommended shooting position leads to ineffective stunning and pain.

Lack of skilled operators, operator fatigue, wrong target area or angle of shooting and inappropriate placement of the gun due to the shape of the head can lead to incorrect shooting position. The animal should be stationary and in the correct position to enable accurate targeting.

<u>Inappropriate power, calibre of the cartridge and type of projectile</u>

Ineffective stunning might occur when the chosen firearm and projectile are inappropriate to cause immediate death. Ineffective killing might occur when using underpowered ammunition designed for use in target shooting, which therefore fails to penetrate; or to using copper-jacketed ammunition which overpenetrates without distorting enough to cause sufficient damage to the brain (HSA, 2016d).

Lack of skilled operator, wrong choice of equipment and cartridge, poor maintenance of the equipment lead to incorrect shooting position

3.2.9.2. Animal-based measures (ABMs) in the context of in the context of 'Firearm with free projectile'

ABMs related to pain and fear during restrain are high-pitched vocalisations, escape attempts, injuries, reluctance to move and turning back (see details in Table 19, Section 3.2.1.1)

ABMs related to pain and fear after stunning are the signs of state of consciousness. The same signs of consciousness that are suggested for penetrative bolt stunning were retrieved from the literature and therefore are suggested here for firearm method (see Table 29 for description of ABMs of state of consciousness and flowchart in Section 3.2.7.2).

3.2.9.3. Prevention and correction of welfare consequences and their related hazards

The use of appropriate firearm and ammunition is essential for preventing poor welfare outcomes.

Furthermore, staff training can help to prevent incorrect position of the shot and inappropriate power, calibre of the cartridge and type of projectile.

Training of staff to use of adequate procedures to monitor (un)consciousness will benefit to prevent and correct shooting failures. Inadequate shooting should be corrected by application of an adequate back-up procedure.

3.2.9.4. Outcome table on 'Firearm with free projectile'

Table 32: Outcome table on 'Firearm with free projectile'

Hazard (see Section 3.2.8.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Incorrect position of the shot	Pain, fear	Staff	Lack of skilled operator, operator fatigue, shooting in wrong place	• Staff training and rotation	Correct shooting position
Inappropriate power and calibre of the cartridge	Pain, fear	Staff, equipment	Lack of skilled operator, wrong choice of equipment and cartridge, poor maintenance of the equipment	• Appropriate equipment, • Staff training	Correct application of the power and calibre
Inappropriate type of projectile	Pain, fear	Staff, equipment	Lack of skilled operator, wrong choice of projectile	• Staff training	Shoot with a correct type of projectile

ABMs: high pitched vocalisations, escape attempts (pain, fear), outcomes of consciousness after stunning (as a prerequisite for experiencing pain and fear).

3.3. Description of Phase 3: Bleeding

3.3.1. Introduction to bleeding process

Bleeding of pigs immediately following stunning is an important step in the slaughter process intended to cause death in unconscious animals. In this phase, animals should first be checked for unconsciousness at the end of stunning through the assessment of indicators of unconsciousness (see Section 3.2).

Under commercial slaughter situations, pigs are bled with a chest stick aimed at severing the common brachiocephalic trunk which gives rise to the carotid arteries that supply oxygenated blood to the brain. Chest sticking is performed by inserting a knife on the ventral aspect of the base of the neck, just in front of the sternum, towards the thoracic inlet (Figures 19 and 20). The size of the sticking wound should be large enough to allow profuse bleeding leading to rapid onset of death in pigs. The blade of the knife should be long enough to reach the brachiocephalic trunk. The size of the sticking incision should be large enough to allow profuse bleeding and rapid onset of death (Anil et al., 1995, 2000).

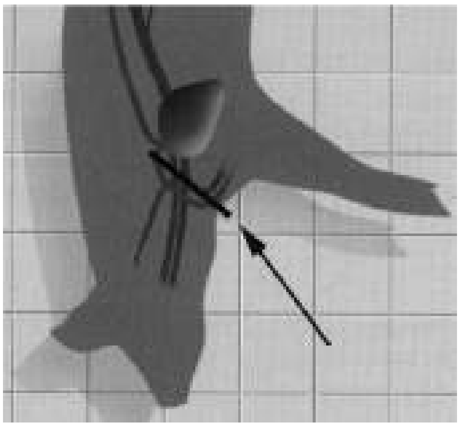

Figure 19: Illustration of chest sticking aimed at cutting the brachiocephalic trunk in a pig (HSA, 2016b)

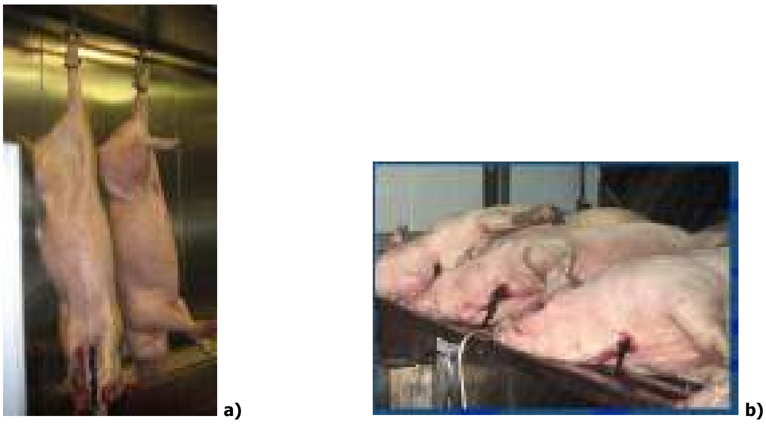

Figure 20: a) Illustration of bleeding pigs on an overhead rail (courtesy of Prof. Lotta Berg); b) Illustration of bleeding pigs on a conveyor (courtesy of Prof. Lotta Berg)

Sticking should be performed swiftly and accurately in unconscious pigs. To avoid recovery of consciousness due to inaccurate or delayed bleeding (prolonged stun to stick interval), irreversible stunning is recommended. Reversible stunning methods induce momentary loss of consciousness and therefore the onus of preventing recovery of consciousness following stunning relies solely on prompt and accurate sticking. It should be ensured that unconsciousness induced by stunning should last longer than the sum of time between the end of stunning and sticking and the time to onset of death due to blood loss following sticking (Figure 21). The bleed out time should be long enough to allow for death to occur in animals and death should be confirmed before carcass processing begins (e.g. entering the scalding tank).

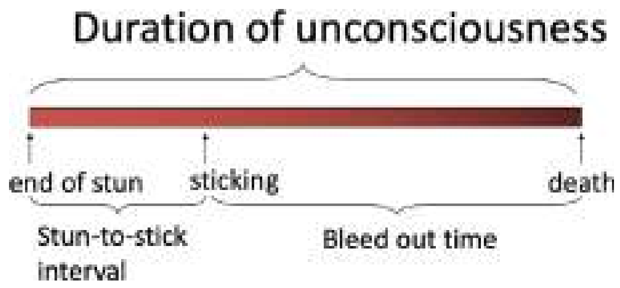

Figure 21: An illustration of the duration of stun-to-neck-cutting and bleeding (from EFSA, 2004)

3.3.1.1. Welfare consequences 'Pain and fear': assessment, hazard identification and management

Definition of 'Pain and fear 'related to bleeding:

The presence of consciousness at sticking or recovery of consciousness during bleeding is a serious animal welfare concern for at least two reasons. First, the incision made in the neck involves substantial tissue damage in areas well supplied with nociceptors (Kavaliers, 1989). The activation of the protective nociceptive system induces the animal to experience pain. Second, onset of death due to sticking is not immediate, and there is a time interval during which if the animal is still conscious can feel negative welfare consequences such as pain and fear (EFSA AHAW Panel, 2013).

ABMs for 'Pain and fear' related to bleeding:

The presence of consciousness during bleeding, leading to pain and fear, can be recognised from the ABMs listed in the third key stage of the flowcharts (EFSA AHAW Panel, 2013) which are reported in Table 33, here below.

In addition, death should be confirmed before dressing and can be recognised by the absence of movements, cessation of bleeding and dilated pupils.

Table 33: ABMs for assessment of 'State of consciousness' during bleeding

ABMs	Description
Sign of consciousness	
Muscle tone	Loss of muscle tone can be recognised from the completely relaxed legs, floppy ears and tail and relaxed jaws with protruding tongue. Ineffectively stunned animals and those recovering consciousness will show a righting reflex and attempts to raise the head (EFSA AHAW Panel, 2013)
Breathing	Ineffectively stunned animals and those recovering consciousness will start to breathe in a pattern commonly referred to as rhythmic breathing, which may begin as regular gagging and involves respiratory cycle of inspiration and expiration. Rhythmic breathing can be recognised from the regular flank and/or mouth and nostrils movement. Recovery of breathing, if not visible through these movements, can be checked by holding a small mirror in front of the nostrils or mouth to look for the appearance of condensation due to expiration of moist air (EFSA AHAW Panel, 2013)
Corneal and/or palpebral reflex	The corneal reflex is elicited by touching or tapping the cornea. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus. Unconscious animals may also intermittently show a positive corneal reflex (EFSA AHAW Panel, 2013)
Blinking	Conscious animals may show spontaneous blinking, and therefore, this sign can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all the conscious animals may show spontaneous blinking (EFSA AHAW Panel, 2013)

ABMs	Description
Posture	Effective stunning will result in immediate collapse or loss of posture in animals that are not restrained or prevented from doing so. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse. (EFSA AHAW Panel, 2013)
Signs of death	
Body movement	Complete and irreversible loss of muscle tone leads to relaxed body of the animal, which can be recognised from the limp carcass (EFSA AHAW Panel, 2013)
Bleeding	Slaughter leads to cessation of bleeding, with only minor dripping, from the neck cut wound, and therefore end of bleeding in both carotid arteries and jugular veins can be used as an outcome of death (EFSA AHAW Panel, 2013)
Pupil size	Dilated pupils (mydriasis) is an indicator of the onset of brain death (outcome of death), the assessment of which requires close examination of the eyes (EFSA AHAW Panel, 2013).

Hazards leading to 'Pain and fear' related to bleeding:

Hazards are:

1) Prolonged stun-to-stick interval
2) Incomplete sectioning of brachiocephalic trunk
3) Sticking of conscious pigs
4) Bleeding to death of conscious animals
5) Dressing of pigs while still alive

Prolonged stun-to-stick interval

It refers to the interval between the end of stunning and sticking being too long to sustain unconsciousness until death occurs due to bleeding when reversible stunning methods are used.

The appropriate stun-to-stick interval needs to be calculated under the prevailing stunning method and slaughter situations. For example, laboratory investigation has shown that the minimum time to return of rhythmic breathing, which is the earliest sign of recovery of consciousness, following effective head-only electrical stunning of pigs is reported to be 37s (Anil, 1991). Research has also shown that, when a chest stick is performed in pigs, the time to loss of evoked potentials in the brain is 22s (Wotton and Gregory, 1986). By subtracting the time to loss of evoked potentials following an accurate sticking from the minimum duration of apparent unconsciousness produced by an accurate stun, the maximum acceptable stun-to-stick interval can be calculated as 15 s.

The results of a field study revealed that about 20% of head-only electrically stunned pigs showed rhythmic breathing as a sign of consciousness during sticking or bleeding when the stun-to-stick interval was 28 s (DEFRA, 2005).

The stun-to-stick interval may be prolonged further if one operator performs head-only electrical stunning on groups (e.g. of four or more) of free-standing pigs in a stunning pen and then performs hoisting and sticking of these pigs. Inevitably, the stun-to stick interval will be considerably longer for the last pig to be stuck in a group. Gas stunning of pigs in small groups may also involve hoisting, moving to bleeding area and sticking in some slaughterhouses. In this situation, if the stunning is reversible, there would be a considerable delay between the end of exposure to gas mixture and sticking for the last pig in a group, which could lead to recovery of consciousness.

Nevertheless, pigs may be stuck on a horizontal conveyor belt (Figure 20b) and this practice is more common when group stunning is performed using CO_2 gas or head-to-body stunning of individual animals in high throughput slaughterhouses and helps to keep stun-to-stick interval short. It should be noted that group stunning of pigs using CO_2 would involve several pigs being emptied from the stunning unit on to the conveyor and they will have to be manipulated to align them for sticking (Atkinson et al., 2012).

It is worth stating that some slaughterhouses may use tubular sticking knives attached to suction pumps that may speed up the bleeding process.

It is also important to note that effective captive bolt stunning of pigs leads to severe convulsions which may impede prompt and accurate sticking, especially if the pig is not restrained appropriately.

Incomplete sectioning of brachiocephalic trunk is the failure to cut the brachiocephalic trunk, which gives rise to carotid arteries, to prevent oxygenated blood supply to the brain.

Various studies have shown that up to 13% of pigs required more than a single sticking attempt to bleed out properly (Anil et al., 2000; Spencer and Veary, 2010),

This hazard can lead to recovery of consciousness. There are no published data concerning this hazard.

Sticking of conscious pigs means that incision of skin, soft tissues, nerves and brachiocephalic trunk of pigs is performed to ineffectively stunned pigs or those recovering consciousness during sticking.

Dressing of pigs while still alive: pigs with signs of life undergoing dressing such as entering the scalding tank. Live pigs can enter the scalding tanks due to poor bleeding.

3.3.1.2. Prevention and correction of welfare consequences and their related hazards

To avoid recovery of consciousness due to inaccurate or delayed bleeding, irreversible stunning is recommended (e.g. head-to-body electrical stunning or prolonged exposure in controlled atmosphere methods). Pigs subjected to head-only electrical stunning should be stuck during the tonic seizure phase to ensure good welfare at slaughter. Therefore, group stunning of pigs should be performed by one operator and hoisting and sticking should be performed by another operative to keep the stun-to-stick interval short. Sticking the pigs on a horizontal conveyor belt helps also keep stun-to-stick interval short.

Preventive measures mainly include training of staff to effectively monitor stun quality using signs of consciousness and signs of recovery of consciousness and to implement speed in hoisting and prompt and accurate sticking, to use sharp knife long enough to reach brachiocephalic trunk and to apply back-up sticking if necessary. The operator should ensure sticking wound is large enough to achieve profuse bleeding and be able to confirm death (by use of signs of death) before pigs enter scalding tank and dressing. The use of tubular sticking knives attached to suction pumps may speed up the bleeding process.

Positioning of the stunner as close as possible to the bleeding rail will help to prevent delay between stunning and bleeding.

3.3.1.3. Outcome table on 'Bleeding'

Table 34: Outcome table on 'Bleeding'

Hazard (see Section 3.3.1.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Prolonged stun-to-stick interval	Pain, fear	Staff, equipment	Lack of skilled operators; delayed hoisting, hoisting and sticking of animals, positioning of the stunner too far away from the bleeding rail	• Staff training; speedy hoisting and hoisting of animals after stunning, prompt and accurate cutting of brachiocephalic trunk; ensuring back-up sticking, if necessary	Backup stunning
Incomplete sectioning of brachiocephalic trunk	Pain, fear	Staff, equipment	Lack of skilled operators, blunt or short knife, narrow sticking wound	• Training of staff, use sharp knife long enough to reach brachiocephalic trunk, ensure brachiocephalic trunk is cut, ensure the sticking wound is large enough to facilitate profuse bleeding	Restun, Cut brachiocephalic trunk correctly
Sticking of conscious pigs	Pain	Staff	Lack of skilled operators, ineffective stun or recovery of consciousness before sticking, lack of monitoring of unconsciousness at the time of sticking	• Apply proper stunning and proper stun to stick interval. Train the staff to monitor consciousness	Apply back-up stunning before sticking
Dressing of pigs while still alive	Pain, fear	Staff	Lack of skilled operators, short bleeding time, incomplete sectioning of brachiocephalic trunk; lack of monitoring of death before carcass dressing	• Staff training • Ensuring death before dressing	None

ABMs: outcomes of consciousness just prior to bleeding (as a prerequisite for experiencing pain and fear).

3.4. Emergency slaughter

Emergency slaughter means killing of animals that are injured or have a condition associated with severe pain or suffering, at arrival or in the lairage, but considered to be fit for human consumption, when there is no other practical possibility to alleviate this pain or suffering. Emergency slaughter can also occur on the farm in animals that are not fit for transport, but considered to be fit for human consumption.

In pigs with severe pain and suffering, emergency slaughter should be carried out at arrival whilst the animal is still on the transport vehicle or during lairage period. It is important to prevent other animals in the group trampling on the recumbent or immobile animal, and therefore, emergency slaughter may have to be performed first before attempting to move other animals from the pen. Conditions that will induce severe pain and suffering are e.g. bone fractures, joint dislocations and open wounds, and animals that are disabled or fatigued.

Manual restraining methods, such as nose snare, boards or operator's legs, can be used to restrict the movement of pigs, if required, to facilitate effective stunning.

Pigs may be killed using captive bolt stunning immediately followed by bleeding or pithing to kill the animal. Head-only electrical stunning followed by bleeding or application of a second electric current cycle across the chest to induce cardiac arrest is another option. The captive bolt parameters and size of the pithing rod should be appropriate for the size of the animal. A minimum current of 1.3Amp should be applied across the head immediately followed by the application of the same current level across the chest, using a 50 Hz sine wave alternating current. The interval between stunning and bleeding, pithing or induction of cardiac arrest should be as short as possible to prevent recovery of consciousness. If firearm with free projectile is the method of choice (e.g. killing of large breeding boars and sows), it is important to select low velocity ammunition that does not exit the skull of the animal or one that disintegrates in the skull of the animal.

The responsible person should ensure that the slaughterhouse has procedures, facilities and equipment for killing these animals outside of the normal slaughter line.

The incidence of emergency slaughter may vary according to the physical condition of the animal, handling and loading facilities on farms, space allowance and climatic conditions during transport. In 2003, the Canadian Food Inspection Agency carried out a survey of 22 slaughterhouses and 13 auction markets and assembly facilities across Canada over the period of 2 months involving a total of 3, 433, 823 boars (hogs) and sows and the data showed that 4, 684 (0.14%) pigs were non-ambulatory at the time of arrival at the slaughterhouse. During transport, 1,372 pigs became non-ambulatory (Appelt, 2003; Canada Gazette, 2004). More importantly, carcasses of 60% of non-ambulatory pigs arriving at slaughterhouses were partially or fully condemned.

Another study carried out in the United States, involving 12,511 pigs at the University of Illinois, showed that 0.85% pigs were non-ambulatory at arrival and increasing the amount of floor space per pig from 0.39 to 0.48 m^2 reduced the percentage of non-ambulatory pigs (0.52 vs. 0.15%; Ritter et al., 2006). Non-ambulatory, non-injured (NANI) pigs are another category subjected to emergency slaughter. In the United States alone approximately 0.5 to 1% of pigs has been characterised as NANI (Carr et al., 2005).

Kozak et al. (2004) monitored reasons for emergency slaughter of pigs, in Czech Republic, during 1997 and 2002 in selected slaughter facilities. The data indicated that the proportion of sows slaughtered due to immobility reasons is high (31.3%) in comparison to other pigs (9.7%). Veterinary inspection of carcass, meat and organs revealed that locomotor apparatus diseases, i.e. pelvic injuries, spinal contusion injuries or injuries of limbs, hind limb paresis, limb injuries, joint and claw inflammations, were more frequent causes of emergency slaughters due to immobility in pigs than general and other conditions, i.e. cachexia and gastrointestinal tract disorders, ataxia, tetany, circulation disorders including heart insufficiency, post-delivery complications, selection and others. In sows, the number of immobile animals with the diagnosis of locomotor apparatus diseases was high (90.0%) in comparison to the general condition and other disease diagnoses (10.0%). The authors concluded that in sows as well as in other pigs, immobility necessitating emergency slaughters is due to unsuitable handling resulting in injuries and paresis of the locomotor apparatus rather than insufficient care leading to general conditions and other diseases (Kozak et al., 2004).

Several factors contribute to overall stress and fatigue in animals, notably, poor preparation of animals on farm prior to loading, pigs response to handling at loading, stress of loading, distance moved from the rearing pen to the loading point, dividing established groups, mixing with unfamiliar group, group size, prodding and, finally, design, construction and maintenance of the loading system itself (Ellis and Ritter, 2006). In general, rough handling on the farm and at slaughterhouse, including inability to recover during lairage (bad conditions and/or insufficient time) can be a significant factor contributing to fatigued animals (Figure 22).

Figure 22: Head-only electrical stunning of a pig on the ramp for the purpose of emergency slaughter (Source: Virginie Michel)

3.5. Unacceptable methods, procedures or practices on welfare grounds

The mandate requests to identify unacceptable methods in terms of welfare.

In this respect, the Panel agrees with Chapter 7.5.10 of the terrestrial code of the World Organisation for Animal Health (OIE, 2019) which defines 'methods, procedures or practices unacceptable on animal welfare grounds' in any species as follow:

1) *Restraining methods which work through electro-immobilisation or immobilisation by injury such as breaking legs, leg tendon cutting, and severing the spinal cord (e.g. using a puntilla or dagger).*
2) *The use of the electrical stunning method with a single application leg to leg.*
3) *The slaughter method of brain stem severance by piercing through the eye socket or skull bone without prior stunning.'*

The same applies for the methods of restraint that are prohibited and listed in European Commission Regulation 1099/2009:

(a) *suspending or hoisting conscious animals*
(b) *mechanical clamping or tying of the legs or feet of animals*
(c) *the use of electric currents to immobilise animals without stunning or killing them under controlled circumstances, in specific any electric current application that does not span the brain.*

In addition, the Panel has serious concerns about the following practices as they will induce severe welfare consequences:

- Unloading or moving severely injured pigs or those unable to move independently without pain or to walk unassisted;
- Use of painful stimuli to move animals (e.g. use of electric goads);
- Lack of drinking water or inappropriate drinking systems at lairage;
- Lack of space at lairage for all animals to lie down at the same time;
- Painful inducing restraint for stunning;
- Painful induction of unconsciousness (e.g. high CO_2 concentration);
- Sticking conscious animals.

These practices should be avoided, re-designed or replaced by other practices, leading to better welfare outcomes.

Most of the hazards originate from staff, and therefore, the Panel considers the lack of skills or lack of training of the staff working in the slaughtering of pigs a serious concern.

3.6. Response to ToR4: specific hazards for animal categories

Some animals can be associated with some specific hazards related to their age, physical characteristics, breed or behavior.

Age

Very young animals (piglets) may be killed for human consumption. Due to their small size (up to 30 kg), they will have specific requirement in terms of handling and moving, e.g. they cannot handle steps or slope of the same range as adults, they need to be more tightly restrained, handle with board at the right level, flooring should be adapted (slatted floor empty space not too wide) etc. They can have specific requirement in terms of feed; therefore, they should be slaughtered immediately or provided with specific feed if requested. When the size of the raceways is not adapted for very small animals, they sometimes have to be carried by hand, and this constitutes an additional hazard leading to fear (pers. comm. from Mélanie Goulinet, DGAl, France, 2020).

If piglets are stun with a head-to-body electrical method, it may be difficult to induce cardiac ventricular fibrillation because, due to the small size of the heart, the current passes through tissues surrounding the heart, rather than through the heart (EFSA, 2004). The electrical resistance of various other tissues in the pathway may also play a role in this. The resistance around the skin can be less than that across the body and the current may not flow through the body, instead on the skin surface. (AVMA, 2000). For that reason, additional care should be taken to ensure effective electrocution.

Furthermore, after penetrative captive bolt, pithing may be difficult to perform in piglets. However, piglets might be killed instantaneously by use of a captive bolt (EFSA, 2004).

Physical characteristics

In some specific breeds (rustic breeds, wild boar etc.) or for animals of large size (breeders), the impedance of the head is very high and therefore requires higher voltages than normally used (minimum 240V).

Some breeds, such as the French breed 'Porc de Bayeux', have large ears, which may interfere with the electrical stunning electrodes placement and therefore additional care should be taken during stunning of those breeds (pers. comm. from Mélanie Goulinet, DGAl, France, 2020).

In general, older pigs and exotic breeds, such as the Vietnamese Pot Bellied Pig with dished forehead impose a particular problem for captive bolt stunning (see Section 3.2.7).

The Mangalica (also Mangalitsa or Mangalitza), Hungarian breed of pig has long fleece covering, which would impose additional hazard, increased electrical resistance, during electrical stunning (see Section 3.2.2). Additional measures should be taken to minimise electrical resistance.

Specific behaviours

In recent years, there has been an increasing demand for wild boar (*Sus scrofa*) meat and a consequent increase in the number of farmed wild boar in the UK[19]. In USA, the demand for feral pig as human food source has also increased over the least 20 years. From 2004 to 2009, at least 461,000 feral pigs were slaughtered for human consumption in Texas alone in USDA-inspected slaughterhouses. Since then, private landowners trap feral pigs and sell them to buying stations and the number of these stations is increasing (Booth, 1995; VerCauteren et al., 2020). However, there are no published scientific data in the literature concerning transport, lairage, stunning and slaughter of wild boar or feral pigs.

Wild boars are generally killed in pens where they are reared. They are generally irreversible stun with a free bullet as it can be used from a distance and requires minimal or no restraint of the animal. The calibre of firearm used depends on the age and size of the animal. For adult sows and boars, a 12-gauge shotgun at short range (5–25 cm from the target) (HSA, 2016d) or at much larger distance (several meters) when they are shoot by hunter in hunting pens.

In certain cases, they can be brought to the slaughterhouse alive. In that case, the breeder trains the wild boar to get into a cage with feed one week before slaughter. The day of slaughter wild boar are transported in an individual cage at the slaughterhouse and they are stunned by captive bolt through the cage for security reasons (pers. comm. from Mélanie Goulinet, DGAl, France, 2020). In

[19] http://www.calu.bangor.ac.uk/Technical%20leaflets/040901%20wildboar.pdf

that case, the captive bolt gun should have a longer bolt and the power of the cartridge should be appropriate as recommended by the manufacturer to overcome the thickness of the skull.

Breeding boars can also be send to slaughter at the end of productive cycle and specific attention during handling is required, as they may be aggressive; they should be kept individually in lairage and the restraining devices should be adjusted to accommodate their large body size.

Some free-range pigs may be more reactive and more prone to jump and run fast and swiftly when they are moved and handled at the slaughterhouse (pers. comm. from Mélanie Goulinet, DGAl, France, 2020).

Even if these specificities do not bring, per se, new hazards, it brings the attention to specific issues that should be addressed to ensure the good welfare condition and stunning efficiency of these specific categories of pigs

3.7. Assessment of uncertainty

Uncertainty related to the occurrence of false-positive and false-negative hazards was assessed (see methodology described in Section 2.2.4).

For evaluation of the risk of occurrence of false-positive hazards in the assessment, the experts elicited for each hazard the probability that it may exist during the slaughter process and should therefore be included in the outcome table. For evaluation of the risk of occurrence of false-negative hazards in the assessment, the experts elicited the probability that at least one welfare-related hazard was missed in the outcome table.

On the possible inclusion of false-positive hazards, the experts were 95–99% certain that all listed hazards occur during slaughter of pigs (i.e. were true positives).

On the possible occurrence of false-negative hazards, the experts were 90–95% certain that at least one hazard was missing in the assessment considering the three criteria for the inclusion of methods and practices in this assessment. The three criteria were: (a). all methods known to the experts that have technical specifications, (b). methods currently used for slaughter of pigs and (c). methods for which the welfare aspects are sufficiently described in the scientific literature.

Furthermore, when considering a global perspective (i.e. including all possible variations to the slaughter practices that are employed in the world and that might be unknown to the experts of the WG.), the experts were 95–99% certain that at least one welfare hazard was missing. This is due to the lack of documented evidence on all possible variations in the processes and methods being practised (see Interpretation of ToRs on the criteria for selection of stunning methods to be included).

4. Conclusions

This mandate asks EFSA to provide an independent view on the slaughter of pigs for human consumption, covering all parts of the slaughter process. The scientific opinion focuses on the identification of hazards leading to negative pig welfare consequences at slaughter. The hazards, their origins, preventive and corrective measures, welfare consequences and related animal-based measures have been identified on the ground of literature search and expert opinion and take into account the common slaughter practices that have been reported in the opinion.

Not all the methods, procedures and practices for slaughter of pigs used worldwide are documented. Due to the lack of adequate description or scientific validation, a hazard analysis was not carried out for these methods, procedures or practices.

Outcome tables have been prepared to summarise the main results of this opinion and include a concise presentation of all retrieved information.

4.1. General conclusions

1) During the slaughter processes, pigs may experience negative welfare consequences such as: heat stress, cold stress, fatigue, prolonged thirst, prolonged hunger, impeded movement, restriction of movements, resting problem, negative social behaviour, pain, fear and respiratory distress.
2) During the slaughter processes, pigs may be exposed to hazards, which could have a cumulative effect on welfare consequences (e.g. water deprivation, insufficient space allowance, too high effective temperature will have a cumulative effect and exacerbate heat stress).

3) Some hazards might persist along processes and phases until the pig is rendered unconscious (e.g. food deprivation).
4) Other hazards might be present only during one phase, but the welfare consequence might persist during the successive processes and phases until the pig is rendered unconscious (e.g. pain due to rough handling).
5) ABMs have been identified for the assessment of all the welfare consequences, except for prolonged hunger and for prolonged thirst at the time of arrival.
6) Most of the hazards identified are associated with lack of staff skills and training (rough handling) and poor-designed and constructed facilities. The Panel considers the lack of skills or lack of training of the staff working in the slaughtering a serious welfare concern.
7) The uncertainty analysis on the set of hazards for each process provided in this opinion revealed that the experts were 95–99% certain that all listed hazards occur during slaughter of pigs. At the same time, the experts were 90–95% certain that at least one welfare-related hazard is missing in this assessment according to the three criteria described in the Interpretation of ToRs (95–99% considering the worldwide situation). This is due to the lack of documented evidence on all possible variations in the processes and methods being practiced.

4.2. Conclusions specific to Phase 1 – pre-stunning

1) The identified welfare consequences at arrival are thermal stress, prolonged hunger and thirst, fatigue and restriction of movement. The corresponding ABMs are panting, discolouration of the skin, shivering, huddling, exhaustion, muscle tremor, dyspnoea, injury and death (dead on arrival).
2) At arrival, ABMs can be only assessed from outside the truck, and therefore, this is only feasible for the animals at the sidewalls of the truck. If welfare consequences are identified for the visible pigs, it is plausible that other pigs in the truck are also affected. If no welfare consequences are identified for the visible pigs, this will not mean that animals that are not in sight are not affected by these welfare consequences.
3) Delayed unloading of animals will lead to persistence or exacerbation of the welfare consequences that originate from the farm or from transport (e.g. prolonged thirst, restriction of movement) and at the same time, it may expose pigs to new hazards leading to additional welfare consequences (e.g. heat stress).
4) At unloading and during handling and moving of the pigs, the three welfare consequences that pigs might experience are pain, fear and impeded movement. They can be assessed using ABMs: injury, lameness, high pitch vocalisation, escape attempts, reluctance to move and turning back, slipping and falling.
5) Unloading severely injured pigs or those unable to move unassisted will exacerbate their pain and is considered a serious welfare concern by the Panel.
6) At lairage, welfare consequences that pigs might experience are negative social behaviour, pain and fear, restriction of movement and resting problems, fatigue, thermal stress, prolonged thirst and hunger. These can be assessed using ABMs: aggressive behavior and mounting, injuries, high pitched vocalisations, muscle tremor, dyspnoea, exhaustion, panting, discolouration of the skin, shivering, huddling, aggression around drinkers.
7) The Panel considers that, at lairage, lack of access to drinking water, lack of shelter for weather protection and lack of space for resting are welfare issues of serious concern as they will prevent the animals to recover from transport or worsen the welfare consequences.
8) During handling to the stunning area pigs might experience impeded movement, pain and fear. These can be assessed using ABMs: slipping, falling, lameness, escape attempt, high pitched vocalisation, injuries, reluctance to move and turning back or turning around.
9) The use of painful stimuli for handling and moving of the animals is considered a serious welfare concern by the Panel.

4.3. Conclusions specific to Phase 2 – stunning

1) Consciousness is a prerequisite for pigs to experience pain, fear and respiratory distress. Therefore, animals that are ineffectively stunned or recover consciousness will be exposed to the hazards and related welfare consequences. Pain, fear and respiratory distress can be

assessed indirectly by assessing the state of consciousness by specific ABMs, which can be used at all key stages.

2) Electrical and mechanical (excluding firearms) stunning methods require restraint that per se may impose additional pain and fear. These welfare consequences will persist during the restraining period until successful stunning.
3) Restraining methods (including conveyors) or practices which cause pain are considered a serious welfare concern by the Panel.
4) Electrical and mechanical stunning methods have the advantage to induce immediate loss of consciousness.
5) Movement of pigs into a single line for the purpose of electrical stunning will cause fear and pain worsened by use of force (e.g. electric goads). The welfare consequences will be exacerbated with increased throughput rates.
6) Electrical stunning of pigs in small groups without restraint may be prone to operator error, as accidental pre-stun electric shocks may be delivered due to slipping of the electrodes.
7) Controlled atmosphere stunning has the advantage of not requiring restraint, but has the disadvantage that it does not lead to immediate onset of unconsciousness.
8) Exposure to CO_2 at high concentrations (defined in this opinion as higher than 80% by volume) is considered a serious welfare concern by the Panel, because it is highly aversive and causes pain, fear and respiratory distress.
9) The exposure to inert gases and CO_2 with inert gases is less aversive as it causes less pain, fear and respiratory distress compared with exposure to CO_2 at high concentrations (defined in this opinion higher than 80% by volume).
10) Exposure to controlled atmosphere stunning can be reversible or irreversible, depending on the gas concentration and duration of exposure. If the exposure to controlled atmosphere stunning does not produce the death of the animal, prolonged interval between the end of the exposure and sticking can lead to recovery of consciousness before sticking or during bleeding.
11) Irreversible stunning methods (e.g. head-to-body electrical stunning) have the animal welfare advantage of eliminating the risk of recovery of consciousness and associated pain and fear.

4.4. Conclusions specific to Phase 3 – bleeding

1) The Panel considers bleeding of ineffectively stunned animals and those recovering consciousness a serious welfare concern, as it leads to severe pain and fear.

5. Recommendations

5.1. General recommendations

1) Design, construction and maintenance of the premises and handling facilities should be based on understanding how pigs perceive their environment and meet their welfare requirements (e.g. thermal comfort, comfort around resting).
2) Even in a well-designed and equipped slaughterhouse, training of staff is a key preventive measure to avoid hazards and mitigate welfare consequences: all processes of the slaughtering should be carried out by trained and skilled personnel. Staff should be trained to consider pigs as sentient beings, to have a good understanding of species-specific behaviour and to act accordingly during all processes.
3) The welfare status (based on the welfare consequences) of pigs should be assessed at each phase of slaughtering to prevent and correct hazards and mitigate negative welfare consequences.
4) The presence of hazards should be monitored by assessing the welfare consequences through ABMs.
5) When the use of ABMs is not feasible and the hazard is present, the pigs should be assumed to experience the related welfare consequences.
6) The ranking of the hazards according to the severity, magnitude and frequency of the welfare consequences for the pigs at slaughtering should be performed in a future scientific opinion in order to prioritise preventive and corrective measures and improve the procedure at slaughter.

7) A standard operating procedure (SOP) should include identification of hazards and related welfare consequences, using relevant ABMs, as well as preventive and corrective measures.
8) The responsible person of the slaughterhouse should put in place actions to prevent the occurrence of hazards. Such measures should include:
    a) the inspection and maintenance of the facilities,
    b) training and rotation of the staff,
    c) appropriate settings and use of the equipment.
9) When a hazard is identified, it should be corrected without any delay.
10) Additionally, measures to prevent and mitigate the welfare consequences should be put in place.
11) Practices leading to serious welfare concerns should be avoided, re-designed or replaced by other practices leading to better welfare outcomes.

5.2. Recommendation specific to Phase 1 – pre-stunning

1) Assessment of the welfare state of pigs at the time of arrival should be performed as an important first step in fulfilling animal protection at slaughterhouse.
2) At arrival, pigs should be unloaded as soon as possible to mitigate the welfare consequences experienced during transport or to prevent other welfare consequences occurring during arrival, including those that are not visible or that cannot be assessed.
3) If unloading is delayed for any reason, hazards inducing thermal stress (too high effective temperature, too low effective temperature) should be prevented (e.g. by providing showering or ventilation).
4) Pigs that are injured, show severe pain, signs of illness or those unable to move independently, should be inspected by a veterinarian and/or trained professional and, if necessary, a procedure for emergency slaughter should be applied as soon as possible to prevent further suffering of the animal.
5) The design, construction and maintenance of the unloading facility, and the aptitude and attitude of the staff should prevent animals from slipping and falling.
6) Pigs should be slaughtered after unloading without any delay. Keeping animals in lairage should be avoided or kept to a minimum.
7) In lairage, it is recommended to ensure all pigs have access to water and protection from adverse weather conditions. Mixing of unfamiliar animals should be avoided.
8) In lairage adequate space should be offered to pigs to stand up, lie down, turn around and escape from aggressors. Space allowance should be calculated through the formula $A = k*BW^{2/3}$ where A is the floor area covered by the pigs and k is a constant value that depends on the pig posture. The minimum k-value should be between 0.036 (in thermoneutral conditions) and 0.047 (if temperature increases above 25°C).
9) If the effective temperature is above the thermoneutral zone, showering should be applied to cool pigs down.
10) Animals should not be forced to move faster than their normal, unhindered walking pace.
11) Painful stimuli, such as electric goads and hitting with a stick, should be avoided. Instead, passive stimuli such as flags, paddles and boards should be used.

5.3. Recommendation specific to Phase 2 – stunning

1) To prevent pigs experiencing pain and fear:
    a) animals should not be hoisted whilst conscious,
    b) animals should not be bled whilst conscious,
    c) death must be monitored and confirmed before pigs are scalded.
2) Restraining methods (including conveyors) or practices which cause severe pain and fear should not be used.
3) Pain and fear associated with restraint should always be assessed by the use of ABMs.
4) Animals should not be restrained if the operator is not ready to stun them immediately.
5) Animals should not be stunned if the operator is not ready to bleed them immediately.

6) Pigs should not recover from stunning since it might expose them to hazards linked with bleeding, causing severe welfare consequences, such as pain and fear.
7) To monitor stunning method efficacy, the state of consciousness of the animals should be checked at each of the three key stages – i.e. after stunning, just prior to sticking and during bleeding – using the suggested ABMs.
8) Animals ineffectively stunned or recovering consciousness should be stunned immediately with a backup method.
9) Exposure to CO_2 at high concentration (defined in this opinion as higher than 80% by volume) should be replaced by exposure to other gas mixtures that are less aversive. More research and development on the composition of non-aversive gas mixtures is needed to eliminate pain, fear and respiratory distress during the induction to unconsciousness.
10) Electrical or mechanical methods can also be considered an alternative, provided that pain associated to the restraining method is kept to a minimum by i. adapting the conveyor to the size of the animal, ii. adapting the throughput rate to the design features of the system, iii. using a lifting system that is not painful, iv. correct handling practices from the operator.
11) For electrical and mechanical stunning methods, more research and development are needed to reduce fear and pain due to the method of restraint.

5.4. Recommendation specific to Phase 3 – Bleeding

1) Recovery of consciousness following reversible stunning methods should be avoided by: (i) prompt and accurate bleeding of animals, (ii) severing completely the brachiocephalic trunk, (iii) making a sticking wound large enough to permit profuse bleeding leading to rapid death.
2) In controlled atmosphere stunning, the duration of exposure should be long enough to induce death and avoid the possibility of recovery due to delay in the sticking.
3) Death must be confirmed before carcass processing (e.g. scalding) begins.

References

Aalhus JL, Schaefer AL, Murray AC and Jones SD, 1992. The effect of ractopamine on myofibre distribution and morphology and their relation to meat quality in swine. Meat Science, 31, 397–409. https://doi.org/10.1016/0309-1740(92)90023-W

Aarnink AJA, Thuy TTH and Bikkera P, 2016. Modelling heat production and heat loss in growing-finishing pigs. CIGR-AgEng conference.

Anil MH, 1991. Studies on the return of physical reflexes in pigs following electrical stunning. Meat Science, 30, 13–21.

Anil MH and McKinstry JL, 1998. Variations in electrical stunning tong placements and relative consequences in slaughter pigs. The Veterinary Journal, 155, 85–90.

Anil MH, McKinstry JL, Whittington PE and Wotton SB, 1995. Effect of the length of the wound on the rate of blood loss and the time to loss of brain responsiveness in pigs. Animal Science, 60, 562.

Anil MH, Whittington PE and McKinstry JL, 2000. The effect of the sticking method on the welfare of slaughter pigs. Meat Science, 55, 315–319.

Appelt M, 2003. Non-ambulatory livestock survey. Report to the Canadian Food Inspection Agency, Canada.

Arduini A, Redaelli V, Luzi F, Dall'Olio S, Pace V and Nanni Costa L, 2017. Relationship between deck level, body surface temperature and carcass damages in Italian heavy pigs after short journeys at different unloading environmental conditions. Animals, 7, 10. https://doi.org/10.3390/ani7020010

Atkinson S, Velarde A, Llonch P and Algers B, 2012. Assessing pig welfare at stunning in Swedish commercial abattoirs using CO_2 group-stun methods. Animal Welfare, 21, 487–495. ISSN 0962-7286. https://doi.org/10.7120/09627286.21.4.487

Averós X, Knowles TG, Brown SN, Warriss PD and Gosálvez LF, 2008. Factors affecting the mortality of pigs being transported to slaughter. Veterinary Record, 163, 386–390.

AVMA (American Veterinary Medical Association), 2000. Report of the AVMA Panel on euthanasia. JAVMA, 218, 669–696.

AVMA (American Veterinary Medical Association), 2020. AVMA guidelines for the euthanasia of animals: 2020 edition. AMVA, Schaumburg, Illinois. 28 pp. Available online: https://www.avma.org/KB/Policies/Documents/euthanasia.pdf

Barton-Gade P and Christensen L, 1998. Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. Meat Science, 48, 237–247.

Barton-Gade P, 2008. Effect of rearing system and mixing at loading on transport and lairage behaviour and meat quality: comparison of outdoor and conventionally raised pigs. Animal, 2, 902–911. https://doi.org/10.1017/s1751731108002000

Beausoleil NJ and Mellor DJ, 2015. Introducing breathlessness as a significant animal welfare issue. New Zealand Veterinary Journal, 63, 44–51. https://doi.org/10.1080/00480169.2014.940410

Becerril-Herrera M, Alonso-Spilsbury M, Lemus-Flores C, Guerrero-Legarreta I, Olmos-Hernández A, Ramírez-Necoechea R and Mota-Rojas D, 2009. CO_2 stunning may compromise swine welfare compared with electrical stunning. Meat Science, 81, 233–237.

Benjamin M, 2005. Advances in pork production, 16, 67.

Berghaus A and Troeger K, 1998. Electrical stunning of pigs: Minimum current flow time required to induce epilepsy at various frequencies. In: Proceedings of the 44th International Congress of Meat Science and Technology, Barcelona. pp. 1070–1081.

Bertol TM, Ellis M, Ritter MJ and McKeith FK, 2005. Effect of feed withdrawal and handling intensity on longissimus muscle glycolytic potential and blood measurements in slaughter weight pigs. Journal of Animal Science, 83, 1536–1542.

Bertol TM, Braña DV, Ellis M, Ritter MJ, Peterson BA, Mendoza OF and McKeith FK, 2011. Effect of feed withdrawal and dietary energy source on muscle glycolytic potential and blood acid-base responses to handling in slaughter-weight pigs. Journal of Animal Science, 89, 1561–1573. https://doi.org/10.2527/jas.2010-2942

Black JL, Mullan BP, Lorschy ML and Giles LR, 1993. Lactation in the sow during heat stress. Livestock Production Science, 35, 153–170.

Blackmore DK, 1995. Energy requirements for the penetration of heads of domestic stock and the development of a multiple projectile. The Veterinary Record, 116, 36–40. https://doi.org/10.1136/vr.116.2.36 PMID: 3976138.

Boissy A, 1995. Fear and fearfulness in animals. The Quarterly Review of Biology, 70, 165–191.

Bolanos-Lopez D, Mota-Rojas D, Guerrero-Legarreta I, Flores-Peinado S, Mora-Medina P, Roldan-Santiago F, Borderas-Tordesillas R, García-Herrera M, Trujillo-Ortega R and Ramírez-Necoechea R, 2014. Recovery of consciousness in hogs stunned with CO_2: physiological responses. Meat Science, 98, 193–197. https://doi.org/10.1016/j.meatsci.2014.05.034

Booth WD, 1995. Wild Boar Farming in the United Kingdom. IBEX J.M.E., 3, 245–248.

Bracke MBM, Herskin MS, Marahrens M, Gerritzen MA and Spoolder HAM, 2020. Review of climate control and space allowance during transport of pigs (version 1.0), Published by EURCAW-Pigs. https://edepot.wur.nl/515292

Brandt P, Dall Aaslyng M, Rousing T, Schild SL and Herskin MS, 2015. The relationship between selected physiological post-mortem measures and an overall pig welfare assessment from farm to slaughter. Livestock Science, 180, 194–202. https://doi.org/10.1016/j.livsci.2015.07.007

Brandt P, Rousing T, Herskin MS, Olsen EV and Dall Aaslyng M, 2017. Development of an index for the assessment of welfare of finishing pigs from farm to slaughter based on expert opinion. Livestock Science, 198, 65–71.

Brent G, 1986. Housing the Pig. Ipswich: Farming Press Ltd.

Brown SN, Knowles TG, Edwards JE and Warriss PD, 1999. Behavioural and physiological responses of pigs being transported up to 24 hours followed by six hours recovery in lairage. Veterinary Record, 145, 421–426.

Brown SN, Knowles TG, Wilkins LJ, Chadd SA and Warriss PD, 2005. The response of pigs to being loaded or unloaded onto commercial animal transporters using three systems. The Veterinary Journal, 170, 91–100.

Canada Gazette, 2004. Regulation amending the health of animals Regulations, Vol. 138.

Carr SN, Gooding JP, Rincker PJ, Hamilton DN, Ellis M, Killefer J and McKeith FK, 2005. A survey of pork quality of Downer pigs. Journal of Muscle Foods, 16, 298–305.

Carstens E and Moberg GP, 2000. Recognizing pain and distress in laboratory animals. ILAR Journal, 41, 62–71.

Correa JA, 2011. Effect of farm handling and transport on physiological response, losses and meat quality of commercial pigs. Advances in Pork Production, 22, 249–256.

Correa JA, Torrey S, Devillers N, Laforest JP, Gonyou HW and Faucitano L, 2010. Effects of different moving devices at loading on stress response and meat quality in pigs. Journal of Animal Science, 88, 4086–4093. https://doi.org/10.2527/jas.2010-2833

Correa J, Gonyou HW, Torrey S, Widowski T, Bergeron R, Crowe T, Laforest JP, Faucitano L, Bergeron T and Crowe R, 2013. Welfare and carcass and meat quality of pigs being transported for 2 hours using two vehicle types during two seasons of the year. Canadian Journal of Animal Science, 93, 43–55. https://doi.org/10.4141/CJAS2012-088

Correia-da-Silva J, Silva A and De Oliveira FE, 2001. Passive cooling in livestock buildings. Conference: Building simulation: Seventh International IBPSA Conference.

Dall Aaslyng MD and Barton-Gade P, 2001. Low stress pre-slaughter handling: effect of lairage time on the meat quality of pork. Meat Science, 57, 87–92. https://doi.org/10.1016/s0309-1740(00)00081-4

Dalla Costa FA, Devillers N, Paranhos da Costa MJR and Faucitano L, 2016a. Effects of applying preslaughter feed withdrawal at the abattoir on behaviour, blood parameters and meat quality in pigs. Meat Science, 119, 89–94. https://doi.org/10.1016/j.meatsci.2016.03.033

Dalla Costa FA, Paranhos da Costa MJR, Faucitano L, Dalla Costa OA, Lopes LS and Renuncio E, 2016b. Ease of handling, physiological response, skin lesions and meat quality in pigs transported in two truck types. Archivos de Medicina Veterinaria, 48, 299–304.

Dalla Costa FA, Dalla Costa OA, Di Castro IC, Gregory NG, Di Campos MS, Leal GBM and Tavernari FC, 2019a. Ease of Handling and Physiological Parameters of Stress, Carcasses, and Pork Quality of Pigs Handled in Different Group Sizes. Animals, 9, 1–9. https://doi.org/10.3390/ani9100798

Dalla Costa FA, Dalla Costa OA, Coldebella A, Lima GJMM and Ferraudo AS, 2019b. How do season, on-farm fasting interval and lairage period affect swine welfare, carcass and meat quality traits? International Journal of Biometeorology, 63, 1497–1505. https://doi.org/10.1007/s00484-018-1527-1

Dalla Costa OA, Dalla Costa FA, Feddern V and Dos Santos Lopes L, 2019c. Risk factors associated with pig pre-slaughtering losses. Meat Science, 155, 61–68.

Dalmau A and Velarde A, 2016. Lairage and handling. In: Velarde A, Raj M (eds.). Animal Welfare at Slaughter. 5 m Publishing. Sheffield, UK. pp. 51–70.

Dalmau A and Velarde A, 2017. Slaughter of pigs. In: Marek Špinka (ed.). Advances in Pig Welfare. Woohead Publishing, London. pp. 295–319.

Dalmau A, Fàbrega E and Velarde A, 2009a. Fear assessment in pigs exposed to a novel object test. Applied Animal Behaviour Science, 117, 173–180.

Dalmau A, Llonch P and Velarde A, 2009b. What the experts say: pig vision and management/handling. Available online: www.pig333.com/what_the_experts_say/pig-vision-and-management-handling_981/

Dalmau A, Temple D, Rodrìguez P, Llonch P and Velarde A, 2009c. Application of the Welfare Quality® protocol at pig slaughterhouses. Animal welfare, 18, 497–505.

Dalmau A, Rodríguez P, Llonch P and Velarde A, 2010. Stunning pigs with different gas mixtures: Aversion in pigs. Animal Welfare, 19, 3.

Dalmau A, Nande A, Vieira-Pinto M, Zamprogna S, Di Martino G, Ribas JCR, Paranhos da Costa M, Halinen-Elemoe K and Velarde A, 2016. Application of the Welfare Quality® protocol in pig slaughterhouses of five countries. Livestock Science, 193, 78–87.

DEFRA (Department for Environment, Food and Rural Affairs), 2005. Evidence project final report MH0110: Electrical stunning in pigs: evaluation of the voltages and frequencies required for effective stunning while maintaining satisfactory carcass quality. DEFRA, London, UK. Available online: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=9846&FromSearch=Y&Publisher=1&SearchText=MH0110&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Dewey C, Haley C, Widowski T, Poljak Z and Friendship R, 2009. Factors associated with in-transit losses of fattening pigs. Animal Welfare, 18, 355–361.

Dokmanovic M, Velarde A, Tomovic V, Clamuclia N, Markovic R, Janjic J and Baltic MZ, 2014. The effects of lairage time and handling procedure prior to slaughter on stress and meat quality parameters in pigs. Meat Science, 98, 220–226.

Edwards LN, Engle TE, Correa JA, Paradis MA, Grandin T and Anderson DB, 2010a. The relationship between exsanguination blood lactate concentration and carcass quality in slaughter pigs. Meat Science, 85, 435–440. https://doi.org/10.1016/j.meatsci.2010.02.012

Edwards LN, Grandin T, Engle TE, Porter SF and Ritter MJ, 2010b. Use of exsanguination blood lactate to access the quality of preslaughter handling pig handling. Meat Science, 86, 384–390.

Edwards LN, Engle TE, Grandin T, Ritter MJ, Sosnicki A, Carlson BA and Anderson DB, 2011. The effects of distance traveled during loading, lairage time prior to slaughter, and distance traveled to the stunning area on blood lactate concentration of pigs in a commercial packing plant. The Professional Animal Scientist, 27, 485–491.

EFSA (European Food Safety Authority), 2004. Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. EFSA Journal 2004;2(7):45, 29 pp. https://doi.org/10.2903/j.efsa.2004.45

EFSA (European Food Safety Authority), 2005. Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to welfare of weaners and rearing pigs: effects of different space allowances and floor. EFSA Journal 2005;3(10):268, 149 pp. https://doi.org/10.2903/j.efsa.2005.268

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2012a. Scientific Opinion on the use of animal-based measures to assess welfare in pigs. EFSA Journal 2012;10(1):2512, 85 pp. https://doi.org/10.2903/j.efsa.2012.2512. Available online: www.efsa.europa.eu/efsajournal

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2012b. Guidance on risk assessment for animal welfare. EFSA Journal 2012;10(1):2513, 30 pp. https://doi.org/10.2903/j.efsa.2012.2513. Available online: www.efsa.europa.eu/efsajournal

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2013. Scientific opinion on monitoring procedures at slaughterhouses for pigs. EFSA Journal 2013;11(12):3523, 62 pp. https://doi.org/10.2903/j.efsa.2013.3523

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2014. Scientific Opinion on the welfare risks related to the farming of sheep for wool, meat and milk production. EFSA Journal 2014;12(12):3933, 128 pp. https://doi.org/10.2903/j.efsa.2014.3933

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2019. Hazard identification for pigs at slaughter and during on-farm killing. EFSA Supporting publication 2019; EN-1684, 10 pp. https://doi.org/10.2903/sp.efsa.2019.en-1684

EFSA (European Food Safety Authority), Hart A, Maxim L, Siegrist M, Von Goetz N, da Cruz C, Merten C, Mosbach-Schulz O, Lahaniatis M, Smith A and Hardy A, 2019. Guidance on communication of uncertainty in scientific assessments. EFSA Journal 2019;17(1):5520, 73 pp. https://doi.org/10.2903/j.efsa.2019.5520

Ekkel ED, Spoolder HAM, Hulsegge I and Hopster H, 2003. Lying characteristics as determinants for space requirements in pigs. Applied Animal Behaviour Science, 80, 19–30.

Ellis M and Ritter MJ, 2006. Management practices and meat quality. pp. 29–32.

EURCAW-Pigs, 2020. European Reference Centre for Animal Welfare Pigs.

Eyes on Animals, 2019. Improving animal welfare in pig slaughterhouses. http://www.eyesonanimals.com/wp-content/uploads/2016/06/Animal-welfare-in-pig-slaughterhouses-how-to-reduce-stress-suffering-and-ease-handling-aanp-1.pdf (accessed on 14/05/2019).

Fàbrega E, Puigvert X, Soler J, Joan T and Dalmau A, 2013. Effect of on farm mixing and slaughter strategy on behaviour, welfare and productivity in Duroc finished entire male pigs. Applied Animal Behaviour Science, 143, 31–39. https://doi.org/10.1016/j.applanim.2012.11.006

Faucitano L, 2001. Causes of skin damage to pig carcasses. Canadian Journal of Animal Science, 81, 39–45. https://doi.org/10.4141/a00-031

Faucitano L, 2010. Invited Review: effects of lairage and slaughter conditions on animal welfare and pork quality. Canadian Journal of Animal Science, 90, 461–469.

Faucitano L, 2018. Preslaughter handling practices and their effects on animal welfare and pork quality. Journal of Animal Science, 96, 728–738. https://doi.org/10.1093/jas/skx064

Faucitano L and Geverink NA, 2008. Effects of preslaughter handling on stress response and meat quality in pigs. In: Faucitano L, Schaefer A (eds.). Welfare of Pigs from Birth to Slaughter. Wageningen Academic Publisher, Wageningen, the Netherlands. pp. 197–224. https://doi.org/10.3920/978-90-8686-637-3

Faucitano L and Goumon S, 2017. Transport to slaughter and associated handling. Advances in Pig Welfare, 261–294.

Faucitano L and Goumon S, 2018. Transport to slaughter and associated handling. In: Marek Špinka (ed.). Advances in Pig Welfare. Woodhead Publishing, London. pp. 261–293.

Faucitano L and Pedernera C, 2016. Reception and unloading of animals. In: Velarde A and Raj M (eds.). Animal Welfare at Slaughter. 5 m Publishing. Sheffield, UK, pp. 33–50.

Fitzgerald RF, Stalder KJ, Matthews JO, Schultz-Kaster CM and Johnson AK, 2009. Factors associated with fatigued, injured, and dead pig frequency during transport and lairage at a commercial abattoir. Journal of Animal Science, 87, 1156–1166.

Forslid A, 1987. Transient neocortical, hippocampal and amygdaloid EEG silence induced by one minute inhalation of high concentrations CO_2 in swine. Acta Physiologica Scandinavica, 130, 1–10.

Fox J, Widowski T, Torrey S, Nannoni E, Bergeron R, Gonyou HW, Brown JA, Crowe T, Mainau E and Faucitano L, 2014. Water sprinkling market pigs in a stationary trailer. 1. Effects on pig behaviour, gastrointestinal tract temperature and trailer micro-climate. Livestock Science, 160, 113–123.

Geers R, 2007. Environmental temperature. In: Velarde A and Geers R (eds.). On farm monitoring of pig welfare. Wageningen Academic Publishers, The Netherlands. pp. 147–157.

Gerritzen MA, Hindle VA, Steinkamp K, Reimert HGM, van der Werf JTN and Marahrens M, 2013. The effect of reduced loading density on pig welfare during long distance transport. Animal, 7, 1849–1857.

Geverink NA, Engel B, Lambooij E and Wiegant VM, 1996. Observations on behaviour and skin damage of slaughter pigs and treatment during lairage. Applied Animal Behaviour Science, 50, 1–13.

Geverink NA, Buhnemann A, van de Burgwal JA, Lambooij E, Blokhuis HJ and Wiegant VM, 1998. Responses of slaughter pigs to transport and lairage sounds. Physiology and Behaviour, 63, 667–673.

Gonyou HW and Brown J, 2012. Reducing stress and improving recovery from handling during loading and transport of market pigs. Final report submitted to Alberta Livestock and Meat Agency, 40

Goumon S, Brown JA, Faucitano L, Bergeron R, Widowski TM, Crowe T and Gonyou HW, 2013. Effects of transport duration on maintenance behavior, heart rate and gastrointestinal tract temperature of market-weight pigs in 2 seasons. Journal of Animal Science, 91, 4925–4935. https://doi.org/10.2527/jas.2012-6081

Grandin T, 1990. Design of loading facilities and holding pens. Applied Animal Behaviour Science, 28, 187–201.

Grandin T, 1991. Principles of abattoir design to improve animal welfare. In: Mathews J (ed.). Progress in Agricultural Physics and Engineering. CAB International, Wallingford, Oxon, U.K. pp. 279–304.

Grandin T, 1996. Factors that impede animal movement at slaughter plants. Journal of the American Veterinary Medical Association, 209, 757–759.

Grandin T, 1997. Survey of Handling and Stunning in Federally Inspected Beef, Pork, Veal and Sheep Slaughter Plants. ARS Research Project No. 3602-32000-002-08G, USDA.

Grandin T, 2000. Effect of animal welfare audits of slaughter plants by a major fast food company on animal handling and stunning practices. Journal of the American Veterinary Medical Association, 216, 848–851.

Grandin T, 2001. Solving return to sensibility problems after electrical stunning in commercial pork slaughter plants. Journal of the American Veterinary Medical Association, 219, 608–611.

Grandin T, 2006. Progress and challenges in animal handling and slaughter in the U.S. Applied Animal Behaviour Science, 100, 129–139.
Grandin T, 2010. Auditing animal welfare at slaughter plants. Meat Science, 86, 56–65.
Grandin T, 2012. Recommended Animal Handling Guidelines and Audit Guide: a Systematic Approach to Animal Welfare. American Meat Institute Foundation, Washington, DC. p. 108.
Grandin T, 2013. Making slaughterhouses more humane for cattle, pigs, and sheep. Annual Review of Animal Biosciences, 1, 491–512.
Grandin T, 2016. Practical methods to improve animal handling and restraint. In: Velarde A and Raj M (eds.). Animal Welfare at Slaughter. 5 m Publishing, Sheffield, UK. pp. 71–90.
Grandin T, 2017. Recommended animal handling guidelines & audit guide: a systematic approach to animal welfare.
Gregory NG, 1998. Livestock presentation and welfare before slaughter. Animal Welfare and Meat Science, 15–41.
Griot B and Chevillon P, 1997. Incidence des matériels utilisés pour manipuler les porcs sur les fréquences cardiaques et les risques d'apparition d'hématomes sur carcasses. Techni-Porc, 20, 39–47.
Griot B, Boulard J, Chevillon P and Kérisit R, 2000. Des restrainers a` bande pour le bien etre et la qualite´ de la viande. Viandes et Produits Carnés, 3, 91–97.
Grist A, Murrell J, McKinstry JL, Knowles TG and Wotton SB, 2017. Humane Euthanasia of Neonates I: Validation of the effectiveness of the Zephyr EXL Non-penetrating Captive Bolt system for euthanasia of new-born and weaned piglets up to 10Kg. Animal Welfare, 26, 111–120.
Grist A, Knowles TG and Wotton SB, 2018a. Humane euthanasia of neonates II: field study of the effectiveness of the Zephyr EXL non-penetrating captive-bolt system for euthanasia of newborn piglets. Animal Welfare, 27, 319–326. https://doi.org/10.7120/09627286.27.4.319
Grist A, Lines JA, Knowles TG, Mason CW and Wotton Stephen B, 2018b. The use of a non-penetrating captive bolt for the euthanasia of neonate Piglets. Animals, 8, 48. https://doi.org/10.3390/ani8040048
Guàrdia MD, Gispert M and Diestre A, 1996. Mortality rates during transport and lairage in pigs for slaughter. Meat Focus International, 10, 362–366.
Guàrdia MD, Estany J, Balasch S, Oliver MA, Gispert M and Diestre A, 2009. Risk assessment of skin damage due to pre-slaughter conditions and RYR1 gene in pigs. Meat Science, 81, 745–751 https://doi.org/10.1016/j.meatsci.2008.11.020
Haley C, Dewey CE, Widowski T and Friendship R, 2008. Association between in-transit losses, internal trailer temperature, and distance travelled by Ontario market hogs. Canadian Journal of Veterinary Research, 72, 385–389.
Hambrecht E, Eissen JJ, Newman DJ, Smits CHM, Verstegen MWA and den Hartog LA, 2005a. Preslaughter handling effects on pork quality and glycolytic potential in two muscles differing in fiber type composition. Journal of Animal Science, 83, 900–907.
Hambrecht E, Eissen JJ, Newman DJ, Smits CHM, den Hartog LA and Vestegen MWA, 2005b. Negative effects of stress immediately before slaughter on pork quality are aggravated by suboptimal transport and lairage conditions. Journal of Animal Science, 83, 440–448.
Hoenderken R, 1978. Elektrische bedwelming van slachtvarkens (Electrical stunning of slaughter pigs). Doctoral Dissertation, University of Utrecht, The Netherlands.
Holst S, 2001. Carbon dioxide stunning of pigs for slaughter – practical guidelines for good animal welfare. 47th International Congress of Meat Science and Technology. Krakow, 1, 48–54.
Honkavaara M, 1989. Influence of lairage on blood composition of pig and on the development of PSK pork. Journal of agricultural science in Finland. Maataloustieteellinen A ikakauskirja, 61, 425–432.
HSA (Human Slaughter Association), 2016a. Humane Handling of Livestock. Available online: https://www.hsa.org.uk/downloads/publications/humanehandlingdownload-updated-2016-logos.pdf
HSA (Human Slaughter Association), 2016b. Captive-Bolt Stunning of Livestock. Available online: https://www.hsa.org.uk/downloads/publications/captive-bolt-stunning-of-livestock-updated-logo-2016.pdf
HSA (Human Slaughter Association), 2016c. Emergency Slaughter. Available online: https://www.hsa.org.uk/emergency-slaughter-introduction/introduction-5
HSA (Human Slaughter Association), 2016d. Humane Killing of Livestock Using Firearms. Available online: https://www.hsa.org.uk/downloads/publications/humane-killing-using-firearms-updated-with-2016-logo.pdf
Huang QF, Gebrewold A, Zhang A, Altura BT and Altura BM, 1994. Role of excitatory amino acid in regulation of rat pial microvasculature. American Journal of Physiology, 266, 158–163.
IASP, 1979. Pain, 6, 250.
Iulietto MF, Sechi P, Mansi Gaudenzi C, Grispoldi Ceccarelli M, Barbera S and Cenci-Goga BT, 2018. Noise assessment in slaughterhouses by means of a smartphone app. Italian Journal of Food Safety, 7, 7053.
Jones TA, 1999. Improved handling systems for pigs at slaughter. PhD Thesis, Royal Veterinary College, University of London, UK.
Kavaliers M, 1989. Evolutionary aspects of the neuro-modulation of nociceptive behaviors. American Zoologist, 29, 1345–1353.
Knowles TG, Brown SN, Edwards JE and Warriss PD, 1998. Ambient temperature below which pigs should not be continuously showered in lairage. Veterinary Record, 143, 575–5798.

Kozak A, Holejsovsky J, Belobradek P, Ostadalova L and Chloupek P, 2004. Emergency slaughter of pigs due to immobility. Veterinary Medicine – Czech, 49, 359–364.
Lambooij E, 1988. Road transport of pigs over a long distance: some aspects of behaviour, temperature and humidity during transport and some effects of the last two factors. Animal Production, 46, 257–263.
Lambooij E and Algers B, 2016. Mechanical stunning and killing methods. In: Velarde A, Raj M (eds.). Animal Welfare at Slaughter. 5M Publishing. Sheffield, UK, pp. 91–110.
Lambooij E and Engel B, 1991. Transport of slaughter pigs by road over a long distance: some aspects of loading density and ventilation. Livestock Production Science, 28, 163–174.
Lambooij E, Garssen GJ, Walstra P, Mateman F and Merkus GSM, 1985. Transport of pigs by car for two days: some aspects of watering and loading density. Livestock Production Science, 13, 289–299.
Lara LJ and Rostagno MH, 2013. Impact of heat stress on poultry production. Animals, 3, 356–369. https://doi.org/10.3390/ani3020356
Le Neindre P, Bernard E, Boissy A, Boivin X, Calandreau L, Delon N, Deputte B, Desmoulin-Canselier S, Dunier M, Faivre N, Giurfa M, Guichet J-L, Lansade L, Larrère R, de Mormè P, Prunet P, Schaal B, Servière J and Terlouw C, 2017. Animal consciousness. EFSA supporting publication 2017;EN-1196, 165 pp. https://doi.org/10.2903/sp.efsa
Llonch P, Dalmau A, Rodríguez P, Manteca X and Velarde A, 2012a. Aversion to N2 and carbon dioxide mixtures for stunning pigs. Animal Welfare, 21, https://doi.org/10.7120/096272812799129475.
Llonch P, Rodríguez P, Gispert M, Dalmau A, Manteca X and Velarde A, 2012b. Stunning pigs with N2 and carbon dioxide mixtures: effects on animal welfare and meat quality. Animal, 6, 668–675. https://doi.org/10.1017/s1751731111001911
Llonch P, Rodríguez P, Jospin M, Dalmau A, Manteca X and Velarde A, 2012c. Assessment of unconsciousness in pigs during exposure to N2 and carbon dioxide mixtures. Animal, 7, 492–498& The Animal Consortium 2012, https://doi.org/10.1017/s1751731112001966
Manteca X, Velarde A and Jones B, 2009. Animal welfare components. Assessment and management of risks, Welfare of production animals. pp. 61–77.
Marahrens M, 2014. Thermal environment & animal thermoregulation during long pig road transport. Presentation at Animal Transport and Certification conference in collaboration with the 40th Annual Global Conference of ATA (Animal Transport Association). http://www.controlpost.eu/controlpost/index.php/en/journal/events/238-final-conference-ofthe-animal-transport-certification-and-control-post-project
McGlone J, McPherson RL and Anderson DL, 2004. Moving devices for finishing pigs: efficacy of electric prod, board, paddle, or flag. The Professional Animal Scientist, 20, 518–523.
Moberg GP, 1987. Problems in defining stress and distress in animals. Journal of the American Veterinary Medical Association, 191, 1207–1211.
Moosavi SH, Golestanian E, Binks AP, Lansing RW, Brown R and Banzett RB, 2003. Hypoxic and hypercapnic drives to breathe generate equivalent levels of air hunger in humans. Journal of Applied Physiology, 94, 141–154.
Mota-Rojas D, Bolas-Lopez D, Mendez MC, Ramirez-Tellez J, Roldan-Santiago P, Flores-Peinado S and Mora-Pedina P, 2012. Stunning swine with CO_2 Gas: Controversies related to animal welfare. International Journal of Pharmacology, 8, 141–151.
Nanni Costa L, 2009. Short-term stress: the case of transport and slaughter. Italian Journal of Animal Science, 8, 241–252. https://doi.org/10.4081/ijas.2009.s1.241
Nodari S, Polloni A, Giacomelli S, Vezzoli F and Galletti G, 2014. Assessing pig welfare at stunning in Northern Italy commercial abattoirs using electrical method. Large Animal Review, 20, 87–91.
Nowak B, Mueffling TV and Hartung J, 2007. Effect of different carbon dioxide concentrations and exposure times in stunning of slaughter pigs: Impact on animal welfare and meat quality. Meat Science, 75, 290–298.
NRC (National Research Council), 1992. Recognition and Alleviation of Pain and Distress in Laboratory Animals. National Academy Press, Washington DC.
O'Malley CI, Wurtz KE, Steibel JP, Bates RO, Ernst CW and Siegford JM, 2018. Relationships among aggressiveness, fearfulness and response to humans in finisher pigs. Applied Animal Behaviour Science, 205, 194–201.
Panella-Riera N, Gispert M, Gil M, Soler J, Tibau J, Oliver MA, Velarde A and Fàbrega E, 2012. Effect of feed deprivation and lairage time on carcass and meat quality traits on pigs under minimal stressful conditions. Livestock Science, 146, 29–37.
Pereira T, Titto EA, Conte S, Devillers N, Sommavilla R, Diesel T, Dalla Costa FA, Guay F, Friendship R, Crowe T and Faucitano L, 2018. Application of a ventilation fan-misting bank on pigs kept in a stationary trailer before unloading: Effects on trailer microclimate, and pig behaviour and physiological response. Livestock Science, 216, 67–74.
Peterson E, Remmenga M, Hagerman AD and Akkina JE, 2017. Use of temperature, humidity, and slaughter condemnation data to predict increases in transport losses in three classes of swine and resulting foregone revenue. Frontiers Veterinary Science, 4, 1–12. https://doi.org/10.3389/fvets.2017.00067
Petherick JC, 1983. A biological basis for the design of space in livestock housing. Farm Animal Housing and Welfare, 103–120.

Pilcher CM, Mike Rojo-Gómez A, Curtis SE, Wolter BF, Peterson CM, Peterson BA, Ritter M and Brinkmann J, 2011. Effects of floor space during transport and journey time on indicators of stress and transport losses of market-weight pigs. Journal of Animal Science, 89, 3809–3818.

Rabaste C, Faucitano L, Saucier L, Mormède P, Correa JA, Giguère A and Bergeron R, 2007. The effects of handling and group size on the welfare of pigs in lairage and their influence on stomach weight, carcass microbial contamination and meat quality. Canadian Journal of Animal Science, 87, 3–12.

Raj ABM, 1999. Behaviour of pigs exposed to mixtures of gases and the time required to stun and kill them; welfare implications. The Veterinary Record, 144, 165–168.

Raj ABM, 2006. Recent developments in stunning and slaughter of poultry. World's Poultry Science Journal, 62, 3.

Raj ABM and Gregory NG, 1995. Welfare Implications of the Gas Stunning of Pigs 1. Determination of Aversion to the Initial Inhalation of Carbon Dioxide or Argon. Animal Welfare, 4, 273–280.

Raj ABM and Gregory NG, 1996. Welfare implications of gas stunning pigs 2. Stress of induction of anaesthesia. Animal Welfare, 5, 71–78.

Raj ABM and Velarde A, 2016. Electrical stunning and killing methods. In: Verlarde A, Raj M (eds.). Animal Welfare at Slaughter. 5M Publishing Ltd, Sheffield, UK. pp. 111–132.

Raj ABM, Johnson SP, Wotton SB and Instry JLM, 1997. Welfare implications of gas sturming pigs: 3. The time to loss of somatosensory evoked potentials and spontaneous electrocorticogram of pigs during exposure to gases. Veterinary Journal, 153, 329–339.

Ritter MJ, Ellis M, Brinkmann J, DeDecker JM, Keffaber KK, Peterson BA, Schilf M and Wolter BF, 2006. Effect of floor space during transport of market weight pigs on the incidence of transport losses at the packing plant and the relationships between transport conditions and losses. Journal of Animal Science, 84, 2856–2864.

Ritter MJ, Ellis M, Murphy CM, Peterson BA and Rojo A, 2008. Effects of handling intensity, distance moved, and transport floor space on the stress responses of market weight pigs. Journal of Animal Science, 8, 43.

Ritter M, Rincker P and Carr S, 2012. Pig handling and transportation strategies utilized under U.S. commercial conditions. London Swine Conference, Canada, pp. 109–120.

Rocha LM, Dionne A, Saucier L, Nannoni E and Faucitano L, 2015. Hand-held lactate analyzer as a tool for the real-time measurement of physical fatigue before slaughter and pork quality prediction. Animal, 9, 707–714. https://doi.org/10.1017/S1751731114002766

Rocha LM, Velarde A, Dalmau A, Saucier L and Faucitano L, 2016. Can the monitoring of animal welfare parameters predict pork meat quality variation through the supply chain (from farm to slaughter). Journal of Animal Science, 94, 359–376.

Rodríguez P, Dalmau A, Ruiz-De-La-Torre JL, Manteca X, Jensen E, Rodríguez B, Litvan H, Velarde A, Irta F, Camps I and Armet , 2008. Assessment of unconsciousness during carbon dioxide stunning in pigs. Animal welfare, 17, 341–349.

Rosen AS and Morris ME, 1991. Depolarizing effects of anoxia on pyramidal cells of rat neocortex. Neuroscience Letters, 124, 169–173.

Rosochacki SJ, Piekarzewska AB, Oszynowicz JPO and Sakowski T, 2000. The influence of restraint immobilization stress on the concentration of bioamines and cortisol in plasma of pietrain and duroc pigs. Journal of Veterinary Medicine Series A, 47, 231–242.

Santos C, Almeida JM, Matias EC, Fraqueza MJ, Roseiro C and Sardina L, 1997. Influence of lairage environmental conditions and resting time on meat quality in pigs. Meat Science, 45, 253–262.

Schmolke SA, Li YZ and Gonyou HW, 2004. Effects of group size on social behaviour following regrouping of growing–finishing pigs. Applied Animal Behaviour Science, 88, 27–38.

Schwartzkopf-Genswein KS, Faucitano L, Dadgar S, Shand P, González LA and Crowe TG, 2012. Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: a review. Meat Science, 92, 227–243.

Spencer BT and Veary CM, 2010. A study of preslaughter pig handling and stunning in selected South African Highveld Region abattoirs. Journal of the South African Veterinary Association, 81, 102–109.

Spensley JC, Wathes CM, Waran NK and Lines JA, 1995. Behavioural and physiological responses of piglets to naturally occurring sounds. Applied Animal Behaviour Science, 44, 277.

Spoolder HAM, Aarnink AAJ, Vermeer HM, Van Riel J and Edwards SA, 2012. Effect of increasing temperature on static space requirements of group housed finishing pigs. Applied Animal Behaviour Science, 138, 229–239. https://doi.org/10.1016/j.applanim.2012.02.010

Steiner AR, Axiak Flammer S, Beausoleil NJ, Berg C, Bettschart-Wolfensberger R, García Pinillos R, Golledge Huw DR, Marahrens M, Meyer R, Schnitzer T, Toscano MJ, Turner PV, Weary DM and Gent TC, 2019. Humanely ending the life of animals: research priorities to identify alternatives to carbon dioxide. Animals, 9, 911. https://doi.org/10.3390/ani9110911

Stocchi R, Aconiti Mandolini N, Marinsalti M, Cammertoni N, Loschi AR and Rea S, 2014. Animal welfare evaluation at a slaughterhouse for heavy pigs intended for processing. Italian Journal of Food Safety, 3, 1712.

Strawford M, Watts J, Crowe T, Classen H and Shand P, 2011. The effect of simulated cold weather transport on core body temperature and behavior of broilers. Poultry science, 90, 2415–2424. https://doi.org/10.3382/ps.2011-01427

Sutherland AM, Pamela B, Nadège K and McGlone J, 2009. The effect of method of tail docking on tail-biting behaviour and welfare of pigs. Animal welfare, 18, 561–570.
Talling JC, Waran NK, Wathes CM and Lines JA, 1996. Behavioural and physiological responses of pigs to sound. Applied Animal Behaviour Science, 48, 187–201. https://doi.org/10.1016/0168-1591(96)01029-5
Talling JC, Waran NK, Wathes CM and Lines JA, 1998. Sound avoidance by domestic pigs depends upon characteristics of the signal. Applied Animal Behaviour Science, 58, 255–266.
Tanida H, Miura A, Tanaka T and Yoshimoto T, 1996. Behavioral responses of piglets to darkness and shadows. Applied Animal Behaviour Science, 49, 173–183.
Terlouw EMC and Gibson T, 2016. Physiology and behaviour of food animals. In: Velarde A and Raj M (eds.). Animal Welfare at Slaughter. 5M Publishing Ltd, Sheffield, UK. pp. 16–32.
Terlouw EMC, Arnould C, Auperin B, Berri C, Le Bihan-Duval E, Deiss V, Lefevre F, Lensink BJ and Mounier L, 2008. Pre-slaughter conditions, animal stress and welfare: current status and possible future research. Animal, 2, 1501–1517https://doi.org/10.1017/s1751731108002723
Terlouw EMC, Bourguet C and Deiss V, 2016. Consciousness, unconsciousness and death in the context of slaughter. Part II. Evaluation methods.. Meat science, 118, 147–156. https://doi.org/10.1016/j.meatsci.2016.03.010
Torrey S, Bergeron R, Widowski T, Lewis N, Crowe T, Correa JA, Brown J, Gonyou HW and Faucitano L, 2013a. Transportation of market-weight pigs: I. Effect of season, truck type, and location within truck on behavior with a two-hour transport. Journal of Animal Science, 91, 2863–2871. https://doi.org/10.2527/jas.2012-6005
Torrey S, Bergeron R, Widowski T, Lewis N, Crowe T, Correa JA, Brown J, Gonyou HW and Faucitano L, 2013b. Transportation of market-weight pigs 2. Effect of season and animal location in the truck on behavior with a 8 hour transport. Journal of Animal Science, 91, 2872–2878 https://doi.org/10.2527/jas.2012–6006
TQA, 2016. National Pork Board Transport Quality Assurance Handbook. Version 6. http://www.pork.org/tqa-certification/tqa-program-materials/
Troeger K, 1989. Plasma adrenaline levels of pigs after different pre-slaughter handling and stunning methods. pp. 975–980.
Troeger K and Woltersdorf W, 1991. Gas anaesthesia of slaughter pigs. Fleischwirtschaft., 71, 1063–1068.
Van de Perre V, Permentier L, De Bie S, Verbeke G and Geers R, 2010. Effect of unloading, lairage, pig handling, stunning and season on pH of pork. Meat Science, 86, 931–937.
Van Putten G and Elshof WJ, 1978. Observations on the effect of transport on the wellbeing and lean quality of slaughter pigs. Animal Regulation Studies, 1, 247–271.
Vecerek V, Malena M, Malena MJR, Voslarova E and Chloupek P, 2006. The impact of the transport distance and season on losses of fattened pigs during transport to the slaughterhouse in the Czech Republic in the period from 1997 to 2004. Veterinarni Medicina, 51, 21–28.
Velarde A, 2008. How can lairage conditions be improved? Animal welfare at slaughter and killing for disease control– emerging issues and good examples. Hindåsgården (Sweden) 1-3 October 2008, pp. 31–36.
Velarde A and Dalmau A, 2012. Animal welfare assessment at slaughter in Europe: Moving from inputs to outputs. Meat Science, 92, 244–251. https://doi.org/10.1016/j.meatsci.2012.04.009
Velarde and Dalmau, 2018. Slaughter of pigs. In: Marek Špinka (ed.). Advances in Pig Welfare. Woodhead Publishing, London. pp. 295–322. https://doi.org/10.1016/B978-0-08-101012-9.00010-1
Velarde A, Gispert M, Faucitano L, Manteca X and Diestre A, 2000. The effect of stunning method on the incidence of PSE meat and haemorrhages in pork carcasses. Meat Science, 55, 309–314. https://doi.org/10.1016/S0309-1740(99)00158-8
Velarde A, Cruz J, Gispert M, Carrión D, de la Torre Ruiz JL, Diestre A and Manteca X, 2007. Aversion to carbon dioxide stunning in pigs: effect of carbon dioxide concentration and halothane genotype. Animal Welfare, 16, 513–522.
VerCauteren KC, Beasley JC, Ditchkoff SS, Mayer JJ, Roloff GJ and Strickland BK, 2020. Invasive Wild Pigs in North America: Ecology, Impacts, and Management, 2020. CRC Press, Taylor & Francis Group, FL. 33487-2742; ISBN 13:978-0-367-86173-5; https://texasfarmbureau.org/market-opens-feral-hog-meat/
Verhoeven M, Gerritzen M, Hellebrekers L and Kemp B, 2015. Indicators used in livestock to assess unconsciousness after stunning: a review. Animal, 9, 320–330.
Verhoeven M, Gerritzen M, Velarde A, Hellebrekers L and Kemp B, 2016. Time to Loss of Consciousness and Its Relation to Behavior in Slaughter Pigs during Stunning with 80 or 95% Carbon Dioxide. Frontiers in Veterinary Science, 3, 38. https://doi.org/www.frontiersin.org/articles/10.3389/fvets.2016.00038/full, viewed June 5th 2019.
Vermeulen L, Van de Perre V, Permentier L, De Bie S, Verbeke G and Geers R, 2015. Sound levels above 85 dB pre-slaughter influence pork quality. Meat Science, 100, 269–274.
Visser EK, Ouweltjes W and Spoolder HAM, 2014. Hazards and adverse effects for the assessment of animal welfare on farm and during transport: A preliminary table for bulls, veal calves and slaughter pigs. Wageningen UR Livestock Research, Research Report 804.
Vitali A, Lana E, Amadori M, Bernabucci U, Nardone A and Lacetera N, 2014. Analysis of factors associated with mortality of heavy slaughter pigs during transport and lairage. Journal of Animal Science, 92, 5134–5141. https://doi.org/10.2527/jas2014-7670

Vogel KD, Badtram G, Claus JR, Grandin T, Turpin S, Weyker RE and Voogd E, 2011. Head-only followed by cardiac arrest electrical stunning is an effective alternative to head-only electrical stunning in pigs. Journal of Animal Science, 89, 1412–1418. https://doi.org/10.2527/jas.2010-2920

Warriss PD, Brown S, Edwards JE and Knowles TG, 1996. Effect of lairage time on levels of stress and meat quality in pigs. proc. EU-Seminar: New information on welfare and meat quality of pig related to handling, transport and lairage conditions. pp. 163–170.

Warriss PD, Brown SN, Knowles TG, Edwards JE, Kettlewell PJ and Guise HG, 1998. The effect of stocking density in transit on the carcass quality and welfare of slaughter pigs: 2. Results from the analysis of blood and meat samples. Meat Science, 50, 447–456. https://doi.org/10.1016/S0309-1740(98)00057-6

Warriss PD, 1994. In: Cole DJA, Wiseman J and Varley MA (eds). Antemortem handling of pigs. In: Principles of Pig Science. Nottingham University Press. pp. 425–432.

Warriss PD and Brown SN, 1994. A survey of mortality in slaughter pigs during transport and lairage. Veterinary Record, 134, 513–515. https://doi.org/10.1136/vr.134.20.513

Warriss PD, Bevis EA, Edwards JE, Brown SN and Knowles TG, 1991. Effect of the angle of slope on the ease with which pigs negotiate loading ramps. Veterinary Record, 128, 419–421.

Warriss PD, Brown SN, Adams SJ and Corlett IK, 1994. Relationships between subjective and objective assessments of stress at slaughter and meat quality in pigs. Meat Science, 38, 329–340 https://doi.org/10.1016/0309-1740(94)90121-x

Weeks CA, 2008. A review of welfare in cattle, sheep, and pig lairages, with emphasis on stocking rates, ventilation and noise. Animal Welfare, 17, 275–284.

Weeks CA, Brown SN, Warriss PD, Lane S, Heasman L and Benson T, 2009. Noise levels in lairages for cattle, sheep and pigs in abattoirs in England and wales. Veterinay Record, 165, 308–314.

Welfare Quality®, 2009. Welfare Quality® assessment protocol for pigs (sows and piglets, growing and finishing pigs). Welfare Quality® Consortium, Lelystad, The Netherlands.

Weschenfelder AV, Torrey S, Devillers N, Crowe T and Bassols A, 2012. Effects of trailer design on animal welfare parameters and carcass and meat quality of three Pietrain crosses being transported over a long distance. Journal of Animal Science, 90, 3220–4676.

World Organisation for Animal Health (OIE), 2019. Terrestrial Animal Health Code. 28th Edition. OIE, Paris. Available online: https://www.oie.int/index.php?id=169&L=0&htmfile=sommaire.htm (accessed on 17 October 2019).

Wotton SB and Gregory NG, 1986. Pig slaughtering procedures: time to loss of brain responsiveness after exsanguination or cardiac arrest. Research in Veterinary Science, 40, 148–151.

Wotton SB and O'Callaghan M, 2002. Electrical stunning of pigs: the effect of applied voltage on impedance to current flow and the operation of a fail-safe device. Meat Science, 60, 203–208.

Xiong Y, Green A and Gates RS, 2015. Characteristics of trailer thermal environment during commercial swine transport managed under U.S. industry guidelines. Animals, 5, 226–244.

Yousef MK, 1985. Thermoneutral zone. In: Yousef MK (ed.). Stress Physiology in Livestock. Vol 1. CRC Press, Boca Raton, Florida, USA. pp. 47–54.

Abbreviations

ABMs	Animal-based measures
AHAW	Animal Health and Animal Welfare
CAS	Controlled atmosphere stunning methods
DoA	Dead on arrival
LCT	Lower critical temperature
LS	Literature search
MSs	Member States
NANI	Non-Ambulatory Non-Injured
NCPs	National Contact Points
OIE	World Organisation for Animal Health
SOP	Standard Operating Procedures
ToR	Term of Reference
UCT	Upper critical temperature
WG	Working group

Appendix A – Literature search outcomes

As described in Section 2.2.1, a literature search was carried out to identify peer-reviewed scientific evidence on the topic of 'slaughter of pigs' that could provide information on the elements requested by the ToRs, i.e.: description of the processes, identification of hazards, origins, preventive and corrective measures, welfare consequences and indicators).

To obtain this, firstly a broad literature search under the framework of 'welfare of pigs at slaughter' was carried out, and the results were successively screened and refined as described below.

Sources of information included in the search: Bibliographic database 'Web of Science'.

The search string was designed to retrieve relevant documents to 'animal welfare' during 'slaughter and killing' of 'pigs'. Restrictions applied in the search string related to the processes characterising 'slaughter and killing' (from arrival to bleeding) of animals, and the date of publication (considering only those records published after EFSA, 2004). No language or document type restrictions were applied in the search string.

Date of the search: 2 December 2019

Web of science search string	
Years 2004–2019	
	Category
Search terms	Field searched
TS=pigs OR TS=pig OR TS=swine OR TS=swines OR TS=piglets OR TS=piglet OR TS=boar OR TS=boars OR TS="sus scrofa"	Topic
AND	
TS=slaughter* OR TS=kill* OR TS=stun*	Topic
AND	
TS=Arriv* OR TS=*load* OR TS=lairage* OR TS=handl* OR TS=mov* OR TS=restrain* OR TS=cut* OR TS=bleed* OR TS=conscious* OR TS=pain* OR TS=behav* OR TS=stress*	Topic
TS=Welf* OR TS="animal welfare"	Topic
Results: 474	
Results after screening:	

Refinement of literature search results

The search yielded a total of 474 records that were exported to an EndNote library together with the relevant metadata (e.g. title, authors, abstract). Titles and abstracts were firstly screened to remove irrelevant publications (e.g. related to species, productive systems, processes and research purposes that were out of the scope of this opinion) and duplicates, and successively to identify their relevance to the topic.

Full text publications were screened if title and abstract did not allow assessing the relevance of a paper. The screening was performed by one reviewer, with support by a second reviewer in cases of doubt; publications that were not considered relevant nor providing any additional value to address the question were also removed. The screening led to 132 relevant records. Discrepancies were discussed between the WG members until a final subset of 59 relevant references was selected and considered in this assessment by reviewing the full papers. The final subset is reported in Table A.1.

Table A.1: List of publications relevant to 'slaughter of pigs' resulting from the Literature Search

ID	Reference
1	Arduini et al. (2017)
2	Atkinson et al. (2012)
3	Averós et al. (2008)
4	Barton-Gade (2008)
5	Becerril-Herrera et al. (2009)
6	Bolanos-Lopez et al. (2014)
7	Brandt et al. (2015)
8	Brandt et al. (2017)
9	Brown et al. (2005)

ID	Reference
10	Correa et al. (2010)
11	Correa et al. (2013)
12	Dalla Costa et al. (2016a)
13	Dalla Costa et al. (2016b)
14	Dalla Costa et al. (2019a)
15	Dalla Costa et al. (2019b)
16	Dalla Costa et al. (2019c)
17	Dalmau et al. (2009c)
18	Dalmau et al. (2010)
19	Dalmau et al. (2016)
20	Dokmanovic et al. (2014)
21	EFSA AHAW Panel (2012a)
22	EFSA AHAW Panel (2013)
23	Fàbrega et al. (2013)
24	Faucitano (2010)
25	Faucitano (2018)
26	Faucitano and Geverink (2008)
27	Fox et al. (2014)
28	Grandin (2006)
29	Grandin (2010)
30	Grandin (2012)
31	Grandin (2013)
32	Grandin (2017)
33	Grist et al. (2018a)
34	Grist et al. (2018b)
35	Iulietto et al. (2018)
36	Llonch et al. (2012a)
37	Llonch et al. (2012b)
38	Llonch et al., (2012c)
39	Nanni Costa (2009)
40	Nodari et al. (2014)
41	Nowak et al. (2007)
42	Panella-Riera et al., 2012;
43	Pereira et al. (2018)
44	Rabaste et al. (2007)
45	Rocha et al. (2016)
46	Rodríguez et al. (2008)
47	Schwartzkopf-Genswein et al. (2012)
48	Spencer and Veary (2010)
49	Terlouw et al. (2008)
50	Van de Perre et al. (2010)
51	Vecerek et al. (2006)
52	Velarde and Dalmau (2012)
53	Velarde et al. (2007)
54	Verhoeven et al. (2015)
55	Vermeulen et al. (2015)
56	Vitali et al. (2014)
57	Vogel et al. (2011)
58	Weeks (2008)
59	Weschenfelder et al. (2012)