

Welfare of sheep and goats during killing for purposes other than slaughter

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare) | Søren Saxmose Nielsen | Julio Alvarez | Dominique Joseph Bicout | Paolo Calistri | Elisabetta Canali | Julian Ashley Drewe | Bruno Garin-Bastuji | Jose Luis Gonzales Rojas | Christian Gortázar Schmidt | Mette Herskin | Miguel Ángel Miranda Chueca | Barbara Padalino | Helen Clare Roberts | Hans Spoolder | Karl Stahl | Antonio Velarde | Arvo Viltrop | Christoph Winckler | Mohan Raj | Denise Candiani | Yves Van der Stede | Virginie Michel

Correspondence: biohaw@efsa.europa.eu

Abstract

Sheep and goats of different ages may have to be killed on-farm for purposes other than slaughter (where slaughter is defined as killing for human consumption) either individually (i.e. on-farm killing of unproductive, injured or terminally ill animals) or on a large scale (i.e. depopulation for disease control purposes and for other situations, such as environmental contamination and disaster management) outside the slaughterhouses. The purpose of this opinion was to assess the hazards and welfare consequences associated with the on-farm killing of sheep and goats. The whole killing procedure was divided into Phase 1 (pre-killing) – that included the processes (i) handling and moving the animals to the killing place and (ii) restraint of the animals before application of the killing methods and Phase 2 – that included stunning and killing of the animals. The killing methods for sheep and goats were grouped into three categories: (1) mechanical, (2) electrical and (3) lethal injection. Welfare consequences that sheep and goats may experience during each process were identified (e.g. handling stress, restriction of movements and tissue lesions during restraint) and animal-based measures (ABMs) to assess them were proposed. During application of the killing method, sheep and goats will experience pain and fear if they are ineffectively stunned or if they recover consciousness. ABMs related to the state of consciousness can be used to indirectly assess pain and fear. Flowcharts including ABMs for consciousness specific to each killing method were included in the opinion. Possible welfare hazards were identified for each process, together with their origin and related preventive and corrective measures. Outcome tables linking hazards, welfare consequences, ABMs, origins, preventive and corrective measures were developed for each process. Mitigation measures to minimise welfare consequences were proposed.

KEY WORDS

animal welfare consequences, animal-based measures, goat, hazards, on-farm killing, preventive measures, sheep

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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 parallel, since 2005, the World Organisation for Animal Health (WOAH, formerly called OIE as referred to in the background of the mandate) has developed two chapters in its Terrestrial Animal Health Code: (i) slaughter of animals (Chapter 7.5) and (ii) killing of animals for disease control purposes (Chapter 7.6). The WOAH has created an ad hoc working group to revise these two chapters.

Against this background, the European Commission requested from EFSA a scientific opinion providing an independent view on the killing of sheep and goats for purposes other than slaughter (in which slaughter is defined as killing animals for human consumption), which includes: (i) on-farm killing of individual animals (unproductive, injured or terminally ill animals) and (ii) large-scale killings (depopulation for disease control purposes and for other situations, such as environmental contamination and disaster management) outside the slaughterhouses.

EFSA was asked to review the most recent scientific publications with the aim to identify the animal welfare hazards present during on-farm killing and their possible origins in terms of facilities/equipment and staff; define qualitative or measurable criteria to assess the effects on animal welfare [animal-based measures (ABMs)]; provide preventive and corrective measures (structural or managerial) to address the hazards identified; and point out specific hazards related to species or types of animals. In addition, the European Commission asked EFSA to also provide measures to mitigate the welfare consequences that can be caused by the identified hazards.

This Scientific Opinion aims to update the above-reported EFSA outputs and to provide the European Commission with a scientific basis for future discussions at international level on the welfare of animals in the context of killing for purposes other than slaughter.

The mandate also requested a list of unacceptable methods, procedures or practices that need to be analysed in terms of the above-mentioned welfare aspects. Chapter 7.5.10 of the WOAH 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 during on-farm killing of sheep and goats. These practices should be avoided, re-designed or replaced by other practices, leading to less severe welfare outcomes. Finally, the Panel provided a list of methods that are highly painful and should not be used on welfare grounds.

The approach used to address the mandate follows the protocol previously developed by EFSA for the on-farm welfare mandates related to the Farm to Fork strategy revision: in summary, for the identification of most elements requested in the mandate (e.g. killing methods, hazards, ABMs, etc.), the protocol is based on expert opinion via group discussion, for the identification of welfare consequences occurring to the animals the protocol is based on a structured expert knowledge elicitation (EKE), whereas for the description of such elements, extensive literature searches were used.

Firstly, the EFSA experts identified the processes related to on-farm killing of sheep and goats that should be included in the assessment.

The killing process is divided into Phase 1 (pre-killing), that includes the processes (i) handling and moving the animals to the killing place and (ii) restraint of the animals before application of the killing methods, and Phase 2, that includes stunning and killing of the animals (for methods that require two steps, one for stunning and another for subsequent killing) or killing only (for methods that simultaneously stun and kill the animals) – hereafter referred to as stunning/killing.

The killing methods that have been identified as relevant for sheep and goats can be grouped into three categories: (1) mechanical; (2) electrical and (3) lethal injection.

Mechanical methods include penetrative captive bolt followed by a killing method (e.g. pithing or sticking), non-penetrative captive bolt followed by a killing method and firearm with free projectile. In the electrical killing methods, head-only electrical stunning is followed (or applied at the same time) by application of the electrical current across the chest to span the heart. Lethal injection includes an overdose of anaesthetic drugs that cause rapid loss of consciousness followed by death.

Secondly, the experts identified the welfare consequences that sheep and goats may experience during each process. For handling and moving (Phase 1), the following welfare consequences were identified as highly relevant via the structured EKE: handling stress, restriction of movements and injuries (including soft tissue lesions and bone lesions). For restraint (Phase 1), the following welfare consequences were identified as highly relevant via the structured EKE: handling stress, restriction of movements and soft tissue lesions. ABMs for the assessment of these welfare consequences were subsequently identified.

For Phase 2 (stunning/killing), the identification of highly relevant welfare consequences was not performed because the killing procedure will inevitably lead to highly relevant welfare consequences, for instance tissue lesions (to neck or skull), but these are an integral part of the process. The killing process should spare animals from unnecessary pain, distress and suffering according to Reg. 1099/2009 and therefore the focus of this opinion for Phase 2 is on minimising pain and fear by rendering the animal unconscious as fast as possible before inducing death.

During application of the killing method, sheep and goats will experience pain and fear if they are ineffectively stunned or if they recover consciousness. Therefore, ABMs related to the state of consciousness can be used to indirectly assess pain and fear. Flowcharts including ABMs for consciousness specific to each killing method were included in the opinion.

Thirdly, the experts produced a list of possible welfare hazards present during each process and identified the origin of each hazard and related preventive and corrective measures.

For the whole killing process, the main hazards were associated with lack of staff skills and training, and poorly designed or constructed facilities.

For electrical methods, the main hazards leading to ineffective stunning are inappropriate restraint, wrong placement of the electrodes, poor electrical contact, too short exposure time and inappropriate electrical parameters. For a single step electrical killing method, a minimum current of 1 A applied for a minimum of 2 seconds delivered using 50 Hz sine-wave alternating current spanning the brain and the heart simultaneously is effective in stunning and killing of sheep and goats. For a two-step electrical killing method, a current of 1 A or more applied for a minimum of 2 seconds delivered using 50 Hz sinewave alternating current across the head spanning the brain and across the chest spanning the heart is effective in stunning and killing sheep and goats.

For captive bolt stunning, the hazards are incorrect position and direction of the shot, incorrect captive bolt parameters and the overheating of the captive bolt gun.

Non-penetrative captive bolt applied on the midline, between the ears, with the chin tucked into the neck is a killing method for lambs and goat kids weighing up to 4.5 kg. It is a reversible stunning method (i.e. leading to non-permanent loss of consciousness) for lambs and goat kids in between 4.5 and 10 kg and there is not enough information to conclude if non-penetrative captive bolt is an effective stunning method for sheep and goats of more than 10 kg.

A percussive blow to the head is currently allowed as a one-step method for killing in Regulation (EC) No. 1099/2009 on lambs and kid goats weighing less than 5 kg. It is an entirely manual process and therefore the impact energy delivered to the brain will vary and may not always be sufficient to induce immediate unconsciousness and death.

Specific hazards were identified in relation to particular types of animals, for example extensively raised animals requiring extra care during handling and restraint.

For all hazards, preventive measures can be put in place with management having a crucial role in prevention. Corrective measures were also identified; 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.

Uncertainty assessment was performed on key conclusions, namely those that are likely to be considered for risk management decisions.

Outcome tables summarising all the mentioned elements requested by the mandate (identification of welfare hazards, origin, preventive and corrective measures, welfare consequences and related ABMs) have been produced for each phase and killing method to provide an overall outcome, where all retrieved information is presented concisely.

1 | INTRODUCTION

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

1.1.1 | Background

The Union adopted in 2009 Council Regulation (EC) No 1099/2009¹ on the protection of animals at the time of killing. This piece of legislation was prepared on the basis of two EFSA opinions respectively adopted in 2004² 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} 2015¹³ and 2017.^{14,15}

In parallel, since 2005, the World Organisation for Animal Health (WOAH – formerly called 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 WOAH).

The WOAH 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 discussions at international level on the welfare of animals in the context of slaughter (i.e. killing animals for human consumption) or other types of killing (killing for other purposes than slaughter).

1.1.2 | Terms of Reference

The Commission therefore considers it opportune to request EFSA to give an independent view on the killing of animals for other purposes than slaughter:

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

The request focuses on the cases of large scale killing which take place in case of depopulation for disease control purposes and for other similar situations (environmental contamination, disaster management, etc.) outside slaughterhouses.

The request also considers in a separate section the killing of unproductive animals that might be practiced on-farm (day-old chicks, piglets, pullets, etc.)

The request includes the following issues:

- handling,
- restraint,
- stunning/killing,
- 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:

- Identify the animal welfare hazards and their possible origins (facilities/equipment, staff),

¹OJ L 303, 18.11.2009, p. 1.

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

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

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

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

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

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

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

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

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

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

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

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

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

¹⁵The 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.

- Define qualitative or measurable criteria to assess performance on animal welfare (animal-based measures),
- Provide preventive and corrective measures to address the hazards identified (through structural or managerial measures),
- Point out specific hazards related to species or types of animals (young, with horns, etc.)

1.2 | Interpretation of the Terms of reference

This Scientific opinion concerns the killing of sheep and goats for purposes other than slaughter, usually referred to as on-farm killing. A separate opinion deals with welfare of sheep and goats at slaughter (EFSA AHAW Panel, 2021) and is referred to in the present document.

The European Commission asked EFSA to provide an independent view on the welfare of sheep and goats during on-farm killing for purposes other than slaughter, which takes place in case of: (a) the large-scale killings (depopulation for disease control purposes and for other similar situations, such as environmental contamination and disaster management) outside the slaughterhouses, and (b) individual on-farm killing of unproductive animals, and the Panel agreed to include, in this latter category, the animals that are injured or terminally ill. For each of these scenarios, several welfare aspects need to be analysed (including e.g. welfare hazards, hazard origins, animal-based measures and corrective measures).

This opinion will use definitions related to the killing of sheep and goats provided by the Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing, which entered into force in January 2013. In this opinion, killing refers to any intentionally applied procedure that causes death of the animal (Regulation 1099/2009).

The phases involved in this operation are (1) handling and (2) stunning/killing methods.

Per each phase, the mandate requests the assessment of hazards, related animal-based measures (ABMs), hazards' origin and preventive/corrective actions. The main methods for on-farm killing of sheep and goats identified can be grouped in three categories: (1) mechanical, (2) electrical and (3) lethal injection. The assessment will be dealt with separately for each method.

Some killing methods (or stunning methods if they have to be applied before killing) require the restraint of the animals; therefore, the restraint is also considered a relevant phase and will be included in the assessment as a separate process in Phase 1.

The opinion reports information from literature which was mainly related to sheep. In most cases, it is assumed that the information is relevant also for goats, except for a few cases, where specific information exists for goats which is explicitly indicated in the text.

The mandate does not require the identification of relevant welfare consequences for animals during the killing process. However, in line with the EFSA guidance on risk assessment in animal welfare (EFSA AHAW Panel, 2012), the identification of welfare consequences that sheep and goats can experience when exposed to hazards is a necessary step for the subsequent identification of hazards required by the mandate. Therefore, in this opinion, welfare consequences were identified per each phase of the killing process. More specifically, as it will be further explained in the next chapters, the methodology developed for the identification of welfare consequences follows the EFSA guidance on risk assessment in animal welfare in the context of the F2F strategy revision (EFSA AHAW Panel, 2022). Welfare consequences were identified for the different phases of the killing process, namely for the (i) handling and (ii) restraint phases. For the killing phase, this step was not performed because the killing procedure will inevitably lead to highly relevant welfare consequences, for instance wounds and injuries, but these are an integral part of the process. The killing process should spare animals from unnecessary pain, distress and suffering according to Reg. 1099/2009. However, the EFSA experts consider that the concepts of distress and suffering might include pain and fear (as physical and emotional components), and therefore, the focus of this opinion is on minimising pain and fear.

It is to be noted that the mandate asks to identify the origins of the hazards in terms of staff or facilities/equipment. 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 premises can cause the hazard. Therefore, for each origin category (staff, premises/equipment), relevant origin specifications have been identified by expert opinion.

The mandate also asks to define qualitative or measurable (quantitative) criteria to assess the effect of hazards on animal welfare (animal-based measures (ABMs)). In some circumstances, no ABMs exist or are feasible to use in the context of on-farm killing of sheep and goats.

This opinion also proposes preventive and corrective measures for the identified hazards; these measures regard two main categories: (1) structural and (2) managerial. When corrective measures for the hazards are not available or feasible, actions to mitigate the welfare consequences caused by the identified hazards are discussed. In addition, it is assessed whether specific categories of sheep and goats might be subjected to specific hazards.

Among the methods that are worldwide used for on-farm killing, EFSA has applied the following criteria for the selection of stunning and killing methods to be included in this assessment:

- a) all methods with described technical specifications known by the experts and not only the methods described in Council Regulation (EC) No 1099/2009, and

- b) methods currently used for stunning/killing of sheep and goats, and those which are still under development but are 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.

Gas killing methods (i.e. CO₂), although not allowed in Council Regulation (EC) No 1099/2009, are described in short as they are reported to be currently under research. For these, the full assessment of welfare consequences, hazards, ABMs and preventive and corrective measures is not performed, but the section reports the findings from published literature.

The mandate also requests a list of methods, procedures or practices deemed unacceptable on welfare grounds. Regarding this request, the Panel is aware of two issues. 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, although scientific risk assessment can support discussions on what practices are deleterious on welfare, the ultimate decisions on acceptability involve, e.g. ethical and socio-economic considerations that need to be weighed by the risk managers in regard to the welfare implications.

In response to this request, 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' pain and the group of those not leading to 'severe' pain. For the practices leading to severe pain, the Panel has serious concerns and therefore recommends that these practices should be avoided, re-designed or replaced by other practices, leading to better welfare outcomes. These practices are 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 EFSA experts was used for a narrative description and assessment of each phase of the stunning and killing process (see relevant Sections 3.2–3.4 in the Assessment chapter).

2.1.2 | Data from expert opinion

The data obtained from the literature were complemented by the EFSA experts' opinion in order to identify hazards, hazards' origins, welfare consequences, ABMs and preventive and corrective measures relevant for the current assessment.

2.2 | Methodologies

2.2.1 | Protocol

This scientific opinion follows the protocol detailed in the methodological guidance developed by the AHAW Panel in the context of the Farm to Fork strategy revision (EFSA AHAW Panel, 2022).

Based on expert opinion through working group discussion, the EFSA experts firstly described the phases involved in the process of on-farm killing and specifically the pre-killing phases (i.e. handling and moving of animals to the killing place and restraint) and the killing phase, involving different stunning/killing methods that are considered in the current assessment.

According to the protocol, EFSA translated the assessment questions into more specific subquestions. These are inter-related, meaning that the outcome of each subquestion is necessary to proceed to the next subquestion. The approach to develop the subquestions is based on using both evidence from the scientific literature and expert opinion. The translation of the assessment questions into subquestions is mapped in Table 1.

As it can be seen, firstly, per each phase of the killing process, the main practices are defined. Secondly, the experts identified the possible welfare consequences characterising each practice related to the killing of sheep and goats.

As explained in the interpretation of the mandate (Section 1.2), the identification of welfare consequences relevant for the animals during a certain practice under assessment was performed, via expert opinion, only for the pre-killing phases (i.e. handling and moving and restraint, see Section 2.2.3) and not for the killing phase, as the focus during that phase is solely on pain and fear.

The experts then identified the hazards leading to the identified welfare consequences (for the pre-killing phase) or leading to pain and fear (for the killing phase), their origin and the related preventive and corrective measures. ABMs for measuring the welfare consequences were also identified. In addition, measures to mitigate the welfare consequences were considered.

The specific protocol for the assessment of each of the subquestions listed in [Table 1](#) and summarised above is presented in [Appendix B](#). Evidence needs and methods used for answering each of the subquestions are presented separately depending on whether they are based on expert opinion ([Table B.1](#) in [Appendix B](#)) or data extracted from literature reviews ([Table B.2](#) in [Appendix B](#)).

TABLE 1 Translation of assessment questions into subquestions and approach per each subquestion.

Assessment questions	Subquestions	
1. Describe the killing phases and practices	1. Describe the killing phases and practices per specific species and animal categories Aim: All the killing phases (e.g. handling and moving, restraint, stunning/killing) and practices listed in the mandate are described narratively for each animal species (e.g. sheep) and animal category (e.g. neonates (up to 5 kg), lamb or adult sheep) Approach: literature review	
2. Identify the welfare consequences	2a. Identify the highly relevant welfare consequences that may occur due to the practices Aim: Highly relevant welfare consequences for each of the previously defined killing practices per species and animal category are identified. As explained before (Section 1.2), relevant welfare consequences are selected for the handling and moving phase and the restraint phase. For the killing phase, the focus is on pain and fear Approach: expert opinion via EKE (see focus on this in Section 2.2.3) Relationship with assessment question: the list of relevant welfare consequences is necessary for the assessment question asking to identify the hazards during the processes	2b. Describe the highly relevant welfare consequences for each animal transport practice Aim: Highly relevant welfare consequences characterising each process related to the killing of sheep and goats are described Approach: Literature review Relationship with assessment question: related to subquestion 2a
3. Define qualitative or quantitative animal-based measures (ABMs) to assess the welfare consequences	3a. Identify feasible ABMs for the assessment of the highly relevant welfare consequences Aim: The ABMs for the assessment of the welfare consequences previously identified as relevant are selected (only for feasible ABMs) Approach: expert opinion via group discussion Relationship with assessment question: this corresponds to the assessment question	3b. Describe feasible ABMs for the assessment of the highly relevant welfare consequences Aim: The ABMs for the assessment of the welfare consequences previously identified as the highly relevant are described Approach: literature review Relationship with assessment question: related to subquestion 3a
4. Identify the hazards and their origin	4a. Identify the hazards leading to the highly relevant welfare consequences Aim: The hazards leading to the highly relevant welfare consequences are identified together with their origin Approach: expert opinion via group discussion Relationship with assessment question: this corresponds to the assessment question and is related to subquestion 2 in which hazards are identified only for the highly relevant welfare consequences	4b. Describe the hazards leading to the highly relevant welfare consequences Aim: The hazards are described Approach: literature review Relationship with assessment question: related to subquestion 4a
5. Provide recommendations to prevent, or correct the hazards or to mitigate the welfare consequences	5a. Identify the preventive and corrective measures for the hazards and mitigative measures for the highly relevant welfare consequences Aim: Preventive and corrective measures for the hazards and mitigative measures for highly relevant welfare consequences for the previously defined killing practices per animal category are identified Approach: expert opinion via group discussion Relationship with assessment question: This corresponds to the assessment question and is related to subquestion 2 in which preventive and corrective measures are identified only for the highly relevant welfare consequences	5b. Describe the preventive and corrective measures for the hazards and mitigative measures for the highly relevant welfare consequences Aim: Preventive and corrective measures for the hazards and mitigative measures for highly relevant welfare consequences are described Approach: literature review Relationship with assessment question: related to subquestion 5a

2.2.2 | Literature search

A literature search was carried out to identify hazards related to animal welfare during on-farm killing of sheep and goats in peer-reviewed and grey literature.

The search focused on the killing process and its hazards. No search was done on the indicators of consciousness and death as these were investigated in detail in a previous EFSA opinion (EFSA AHAW Panel, 2013a).

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, 2006).

A total of 118 references were retrieved and reviewed by the EFSA experts to select potentially relevant references. Discrepancies were discussed between the EFSA experts until a final subset of 18 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 EFSA experts selected relevant references starting from scientific papers, including review papers, book chapters, non-peer-review papers known by the experts themselves or retrieved through non-systematic searches, until the information of the subject was considered sufficient to undertake the assessment by the EFSA experts. If needed, relevant publications before 2004 were considered.

2.2.3 | Expert opinion

As described in Table 1, expert opinion was used for the subquestions requiring the identification of welfare consequences, ABMs, hazards, preventive and corrective or mitigative measures.

Expert opinion was mainly elicited via EFSA expert group discussion. Only for the identification of highly relevant welfare consequences (pre-killing phase and restraint), a structured Expert Knowledge Elicitation (EKE) was carried out. This involved an exercise of classification of welfare consequences by the experts first at individual level, followed by group discussion to identify the highly relevant ones by consensus.

The starting point was the list of 33 specific welfare consequences identified by the AHAW Panel in the methodological guidance produced in the context of the F2F strategy revision (for details, see section 3.1.1.3, EFSA AHAW Panel, 2022).

The exercise was carried out separately for each of the animal killing phases and practices resulting from Sub-question 1 (i.e., [i] handling and moving and [ii] restraint).

The exercise consists in selecting the highly relevant welfare consequences out of these 33 for each of these combinations.

For each combination, the EFSA experts classify, based on an estimate of their magnitude, the 33 welfare consequences into four categories of relevance: (i) non-applicable, e.g. the welfare consequence 'inability to perform suckling behaviour' is not considered relevant for the animal categories covered by the mandate, (ii) slightly relevant, e.g. the welfare consequence 'inability to perform play behaviour' might apply, but its effect on welfare (in terms of prevalence and/or severity) was considered to be minimal compared to other welfare consequences of the killing practices, (iii) moderately relevant and (iv) highly relevant. The magnitude of a welfare consequence is defined as the product of three parameters (severity, duration and frequency of occurrence) (EFSA AHAW Panel, 2012). Severity refers to the intensity of the welfare consequence. Duration refers to the time an animal spends within a specific killing scenario while the occurrence refers to the prevalence of animals experiencing the welfare consequence in that specific scenario.

Owing to the lack of published data on these three parameters, the EFSA experts expressed their qualitative expert opinion on the magnitude of welfare consequences.

Expert opinion was elicited in three phases:

1. First phase: The four EFSA experts individually screened the list of welfare consequences and identified those that would fall in the 'non-applicable' or 'slightly relevant' categories. Their individual judgements were then be collated, and those welfare consequences unanimously identified as belonging to these two categories were removed and not considered for further assessment. Those welfare consequences for which there was no consensus whether they could be considered 'non-applicable' or 'less relevant' remained for further assessment and required an open group discussion to find a consensus.
2. Second phase: The experts individually screened the list of remaining welfare consequences and identified those that would fall in the category of 'highly relevant' in order to identify only the highly relevant welfare consequences that could be kept for further assessment procedure (Subquestion 5, section 3.1.1.2). Similarly, as during the first phase in case discrepant opinions emerged, consensus was sought through group discussion.
3. Third phase: The experts were asked to rank individually all the remaining welfare consequences in the list that were not already identified as highly relevant (and thus kept) or non-applicable or slightly relevant (and thus removed) from the highest to the least relevant. Their individual rankings were then discussed again in an open group discussion with the aim to assign the remaining welfare consequences into the category 'highly relevant' or in the category 'moderately relevant'.

The scientific opinion only reports, for each of the defined animal killing practices, those welfare consequences that were selected to be highly relevant from this exercise.

2.2.4 | Structure of the opinion

Chapters are organised by phases of the killing process. In particular, Phase 1 is the pre-killing phase and includes two practices, i.e. 'Handling and moving' and 'Restraint'. Phase 2 is the 'Killing' practice (i.e. application of stunning/killing method). In Phase 1, welfare consequences are presented in a list and hazards are included within the related welfare consequences. Within Phase 2, subchapters are organised by stunning/killing methods and the focus is on pain and fear for all stunning methods. Hazards are specifically listed within each stunning method.

At the end of each phase, an outcome table summarises the assessment performed linking all the elements requested by the mandate.

2.2.5 | Uncertainty assessment

The uncertainty in the assessment performed for this Scientific Opinion was investigated in a qualitative manner following the procedure detailed in the EFSA guidance on uncertainty analysis in scientific assessments (EFSA Scientific Committee, 2018a, 2018b).

The Panel agreed to tackle the uncertainty related to the methodology employed to identify welfare consequences, ABMs and related hazards by describing its potential sources. A table describing the sources of uncertainty is presented in Appendix C.

Regarding the overall impact of the identified uncertainties on the conclusions of the opinion, it was agreed to perform an assessment only for a subset of key conclusions that could be considered for risk management decisions (e.g. those on the application of the stunning and killing methods).

These conclusions were rephrased into well-defined scientifically answerable assessment questions referring to quantities of interest related to a significant proportion of animals in the population, with proportions varying depending on the context of the question (e.g. a 99% threshold ensures that the quasi totality of animals is effectively stunned).

Experts were then asked to provide their judgement on the certainty for each question according to three predefined agreed certainty ranges (Table 2 here below), which are derived from the approximate probability scale from the guidance on uncertainty (EFSA Scientific Committee, 2018a, 2018b).

TABLE 2 Three ranges used to express agreed (consensus) certainty around conclusions.

	Certainty range		
Quantitative assessment	> 50%–100%	66%–100%	90%–100%
Qualitative translation	More likely than not	From likely to almost certain	From very likely to almost certain

Experts were first asked to individually identify the certainty range better reflecting their degree of certainty for each conclusion, and then, a group discussion was held during which they had the chance to explain the rationale behind their judgement; finally, a consensus on which range better reflected the overall certainty was reached and, if no consensus was achieved, the wider range encompassing all individual judgements was selected.

3 | ASSESSMENT

3.1 | Introduction to on-farm killing practices

There are several reasons for killing sheep and goats on farm other than slaughter for human consumption. Two main situations can be identified: (i) on-farm killing of individual animals (unproductive, injured or terminally ill animals) and (ii) large-scale killings (depopulation for disease control purposes and for other situations, such as environmental contamination and disaster management) outside the slaughterhouses. On-farm conditions differ from slaughterhouses, especially during the killing for disease control due to lack of handling and restraining facilities for the specific purpose. This also implies that various stunning/killing methods used in slaughterhouses may not work efficiently or are not applicable for killing on farms. Additionally, when it concerns control of infectious diseases, the required speed of action places extra pressure on personnel (Gerritzen & Raj, 2009). All the currently available killing methods for sheep and goats are applied to individual animals. In some cases, a flock of animals may be moved to a holding pen and subsequently divided into more manageable smaller groups and moved to a designated pen where killing methods will be applied individually to the animals.

AVMA (2020) recommends the following methods for on-farm killing of sheep and goats: lethal injection (barbiturates and barbituric acid derivatives), firearms, electrical methods, penetrative and non-penetrative captive bolt. Death should preferably be induced by a single-step killing method or alternatively by a two-step process involving application of a stunning method immediately followed by a killing procedure (Table 3). At the present time, an adjunctive method such as exsanguination, pithing or intravenous injection of a saturated solution of potassium chloride or magnesium sulfate is recommended to ensure death in unconscious animals when penetrative captive bolt stunning or another reversible

stunning method is used. Some methods are used to kill adult or juvenile sheep and goats, while others are mainly applied to neonatal animals.

Animals may be killed in their home pens or moved to the point of kill depending upon the farming practice, flock size, epidemiology of the disease, circumstances (e.g. flood) and available resources. Extensively reared animals may be herded into temporary field pens and killed in situ or moved to the point of kill to facilitate carcass disposal. The roles and responsibilities of individual operators should be clearly identified for effective killing. The responsible person should ensure that the farm has relevant SOPs and contingency plans, and that facilities and equipment for killing animals are available on site. People involved in killing of animals should be trained and have a certificate of competence. Equipment used for killing animals should be checked to ensure it is fit for the purpose.

TABLE 3 Methods used for on-farm killing of sheep and goats and respective animal categories.

Method	Number of steps	Animal category
Electrical method 1: head-only electrical stunning followed by electrical fibrillation of the heart	Two 1. electrical stunning 2. electrical fibrillation of the heart (killing method)	<ul style="list-style-type: none"> • Adults • Lambs and goat kids • Neonates (up to 5 kg)
Electrical method 2: electrocution (head to body)	One	<ul style="list-style-type: none"> • Adults • Lambs and goat kids • Neonates (up to 5 kg)
Lethal injection	One	<ul style="list-style-type: none"> • Adults • Lambs and goat kids • Neonates (up to 5 kg)
Penetrative captive bolt followed by a killing method	Two 1. penetrative captive bolt 2. killing method (e.g. pithing, lethal injection)	<ul style="list-style-type: none"> • Adults • Lambs and goat kids • Neonates (up to 5 kg)
Non-penetrative captive bolt	One	Neonates
Percussive blow to the head	One	Neonates
Firearm	One	<ul style="list-style-type: none"> • Adults • Lambs and goat kids • Neonates (up to 5 kg)

3.1.1 | Reasons for large-scale killing

Large-scale killing on farm or depopulation of sheep and goats may be necessary for several reasons: for the control or eradication of certain animal diseases, to deal with a natural disaster situation such as flood, storm, fire, severe drought and earthquake, as an emergency intervention during feed contamination, as an economic mitigation measure during oversupply or closed marketing channel, outbreak of a highly contagious disease among human population and, as a consequence, closure of slaughterhouses or movement restriction (e.g. SARS-CoV2 during COVID-19), or to decrease the risk of a zoonotic disease infecting humans (FAWC, 2012).

Indeed, contingency plans exist in most countries to deal with disease outbreaks (e.g. AUSVETPLAN, 2015; DEFRA, 2019), but they do not necessarily include natural disasters such as floods. Nevertheless, Gavinelli et al. (2014) have suggested a 'scenario planning', namely a method for preparation to an outbreak, allowing planners to anticipate the problems, re-evaluate their assumptions and reflect on the consequences of different options when developing more resilient strategies. Gavinelli et al. (2014) have suggested that scenario planning should include considerations on animal housing and farming environments, availability of killing methods and competent personnel. The authors have also identified three critical control points: live animal handling, stun/kill efficacy and humaneness, and confirmation of death. These control points can be monitored and corrective actions taken, when necessary. To achieve this, it is important to assess the farm, in particular its size, location, species, categories and age of the animals, available handling facilities, accessibility of the farm and potential obstructions. When choosing the killing method, key points to be considered are its capacity to kill the animals in a timely and controlled way, its compatibility with the available restraint facilities, location on farm for its application and required services (e.g. electrical supply).

It is also important to ensure neonatal, sick and infirm animals are prioritised, restrained individually and killed in situ; animals likely to harm each other should be penned separately; and normal husbandry and feeding should continue up to the time of killing (Gavinelli et al., 2014).

3.1.2 | Reasons for killing of individuals or of a small number of animals

There are different reasons for on-farm killing of one animal or several animals. One reason is the killing of individual animals that are seriously injured or have a disease associated with pain or suffering and where there is no other practical

possibility to alleviate this pain or suffering. Additionally, animals may be killed due to the likelihood of suffering in the immediate future and where remedial care is not considered possible or appropriate. Secondly, non-viable neonates may also be killed to prevent further suffering.

3.2 | Phase 1 (pre-killing): Handling and moving to the killing areas

Handling is the process of preparation of the animals for the killing, and sometimes it involves moving them from the home pen to the killing point. This is for example the case of large-scale killing for depopulation in the case of infectious disease outbreak. Handling and moving can be very stressful to sheep and goats, especially when they are isolated out of their home pens. Gavinelli et al. (2014) list animal handling among one of the key stages when monitoring on-farm killing.

The extent of animal handling facilities required may vary according to the farming conditions and the resources available on the farm to kill the animals without any delay. Transport, pre-slaughter handling and slaughtering have been reviewed by Cockram and Velarde (2022) and some of the risk factors and associated animal welfare consequences will also be relevant to on-farm killing. Sheep have a very strong flocking behaviour, an aversion to social isolation and a following behaviour (following each other). These behaviours can be beneficial to handle them in large numbers to the killing area. Handling and movement that involve separating or disrupting groups is contrary to the natural behaviour of sheep (Hargreaves & Huston, 1997). Sheep become distressed when visually isolated from other sheep, they vocalise and become difficult to handle, making frequent escape attempts to rejoin other sheep (Baldock & Sibly, 1990; Syme & Elphick, 1982).

The use of trained leader sheep and trained dogs can facilitate movement of sheep, especially under extensive conditions. Sheep move away from humans or dogs when their flight zone is penetrated (Hargreaves & Huston, 1997). The flight distance of sheep may vary according to their previous experience with human or dog contact (Hargreaves & Huston, 1990).

Sheep are sensitive to distractions, such as moving or shiny objects and shadows in the raceways, and they will baulk.¹⁶ Sheep are likely to move more easily into a well-lit area than a dark area (Hitchcock & Hutson, 1979). Sheep have a total visual field ranging from 190° to 306° with a binocular field ranging from 4° to 77°. Conformation of the head, presence or absence of horns, position of the ears and length of wool on the face affect the field of view (Hutson, 1980). They can distinguish between colours, contrasting shades and patterns (Sugnaseelan et al., 2013). Sheep have good depth perception (Walk & Gibson, 1961), but this can cause sheep to baulk if there is a change in the floor surface (Hargreaves & Huston, 1997).

In general, goats are less fearful of humans than sheep (AWC, 2020), and they are also often used to close human contact on the farm. Therefore, the EFSA experts consider that handling and moving can be done with minimum stress and relative ease. Goats exhibit fewer fright responses and might be less reactive when pushed to move and those handling them should be aware of this.

3.2.1 | The highly relevant welfare consequences identified for handling and moving

As explained in Section 2.2.1, an exercise based on expert knowledge elicitation was performed to identify the highly relevant welfare consequences for Phase 1 – handling and moving. An overview of the results is presented in Table 4 below.

TABLE 4 Welfare consequences identified as most relevant for Phase 1 – handling and moving.

Phase 1: Handling and moving to the killing area	
Welfare consequence	
Handling stress	
Restriction of movements	
Soft tissue lesions and integument damage	Grouped together under 'Injuries'
Bone lesions (incl. fractures and dislocations)	

Although bone lesions might not be frequent during on-farm killing of small ruminants in Europe, the EFSA experts agreed it should be taken into account when considering the worldwide situation.

It was noted that the two welfare consequences (i) soft tissue lesions and integument damage and (ii) bone lesions will have the same hazards, preventive and corrective measures. For this reason, to avoid repetition of text, they will be presented in the same section under the common term 'Injuries' which will therefore be referred to as from here onward to indicate these two welfare consequences.

¹⁶<https://www.grandin.com/RecAnimalHandlingGuidelines.html>.

In summary, the welfare consequences that sheep and goats might experience during handling and moving to the killing area are 'restriction of movements', 'handling stress' and 'injuries'. The description and assessment of these welfare consequences are provided in this section.

3.2.2 | Welfare consequence 'restriction of movements': Assessment, hazard identification and management

Definition of 'Restriction of movements'

The animal experiences stress and/or negative affective states such as pain, fear, discomfort and/or frustration because it is unable to move freely or is unable to walk comfortably (e.g. due to overcrowding, unsuitable floors, gates, barriers ...).

ABMs for 'Restriction of movements'

Animal welfare, as affected by restriction of movement, can be assessed during handling and moving of the animals by recording the number and proportion of animals slipping, falling and trampling (for goats: Battini et al., 2015; for sheep: Dwyer et al., 2015). Descriptions are provided in Table 5.

TABLE 5 ABMs for the assessment of 'Restriction of movements' during handling and moving of the animals.

ABM	Description
Slipping	Loss of balance, in which the animal loses its foothold or the hooves slide on the floor surface. No other body parts except hooves and/or legs are in contact with the floor surface (for goats: Battini et al., 2015; for sheep: Dwyer et al., 2015)
Falling	Loss of balance, in which part(s) of the body other than feet and legs are in contact with floor surface (for goats: Battini et al., 2015; for sheep: Dwyer et al., 2015)
Trampling	Stamping, pawing, walking or standing on other animals (Jones et al., 2010)

Hazards leading to 'Restriction of movements'

The impairment of animal welfare at this stage is mainly due to one hazard:

Inadequate facilities

If the passageways from the pen area to the killing point are not well designed (angle of the slope, type of floor, etc.) or constructed and maintained (slippery, etc.), this could lead to restriction of movements. Passageways are inadequate if they present right angles because lead animals cannot be seen by followers, and similarly solid boards obstruct the visual contact with other animals.

Prevention and correction of 'Restriction of movements' and its related hazards

Sheep being gregarious animals will follow each other and they should be allowed to follow others without force. For both sheep and goats, slipping and falling can be prevented by keeping the passageways clean and dry, e.g. by adding saw dust. Animals move easily from dark to light areas, and therefore, lighting conditions should be adjusted to facilitate free movement of animals. Right angles in passageways should be avoided so that followers do not lose sight of lead animals. Curved passageways should rather be used, and solid boards avoided.

To prevent restriction of movements, obstacles or distractions should be avoided in order to avoid animals baulking and/or turning back, impeding the flow.

In addition, animals should not be forced to move faster than their normal and unhindered walking pace.

3.2.3 | Welfare consequence 'handling stress': Assessment, hazard identification and management

Definition of 'Handling stress'

The animal experiences stress and/or negative affective states such as pain and/or fear resulting from handling and moving.

ABMs for 'Handling stress'

Handling stress may result in attempts to escape, reluctance to move due to fear of humans or dogs. Escape attempts may result in the animal slipping and falling or colliding with fences, walls or pen fixtures. Animals may also vocalise more when handled inappropriately (Table 6).

TABLE 6 ABMs for the assessment of 'Handling stress' during handling and moving of the animals.

ABM	Description	Welfare consequence
Escape attempts	Attempts to go through, under or over gates and other barriers (for goats: Battini et al., 2015; for sheep: Dwyer et al., 2015)	Handling stress
Reluctance to move	An animal that refuses to move when coerced by the operator or that stops for at least 4 seconds not moving the body and the head (freezing) (modified after Battini et al., 2015 for goats; Dwyer et al., 2015- for sheep)	Handling stress
Vocalisations	Bleating in goats and in lambs (Goldberg, 2018). This does not apply to adult sheep as usually they do not vocalise	Handling stress

Hazards leading to 'Handling stress'

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

1. Inappropriate handling by humans
2. Inappropriate use of dogs
3. People entering the pen/holding area
4. Unexpected loud noise

Inappropriate handling by humans

Inappropriate handling may occur when animals are reluctant to move and there is an increased pressure to move them as a group for example due to limited time availability. Therefore, the operator might push, pull the wool or hold the animals by the skin (Gregory, 2009).

It is also considered inappropriate handling when staff move single animals, especially for sheep since they are gregarious animals. Goats might be less gregarious, and therefore, the risk of inappropriate handling by moving single animals is lower.

The retina of sheep and goats is most sensitive to yellowish green (552–555 nm) and bluish purple light (444–455 nm) (Jacobs et al., 1998) which may explain why yellow safety vests may be a major distraction in these species.

Inappropriate use of dogs

The use of untrained or overly excitable dogs in the field or inappropriate use of trained dogs in enclosed spaces can cause sheep to become frightened, move abruptly or crowd and avoid contact with the dog and consequently collide with each other, potentially injuring themselves (Dwyer, 2009).

People entering the pen/holding area

To move animals or to perform the killing of animals in the pen people need to enter the house. Sheep and goats can be fearful of humans at different degrees: Goats are usually less fearful of humans than sheep and therefore maybe less exposed to this hazard.

Stressed sheep are not easy to handle. Stress of animals is more likely to occur when non-familiar humans or people dressed in colours (that they are not used to, for instance yellow jackets and personal protective equipment) are entering the pen.

Unexpected loud noise

The auditory range of sheep is 125 Hz to 40 kHz with the most sensitive frequency a little higher than cattle and pigs at 10 kHz (Heffner & Heffner, 1992). Sheep appear to adapt to increased noise levels, particularly when these are relatively continuous (Hall et al., 1998). Kim et al. (1994) noted that sheep in lairage appeared more fearful to human vocalisation and to mechanical noise such as metal banging and hosing than to noises of animal origin, and these variables may exist during on farm killing also.

No information was found on reaction to unexpected noise in goats, but it can be assumed that they can also get frightened by loud noises.

Other sources of loud noise are barking dogs.

Prevention and correction of 'Handling stress' and their related hazards

To prevent handling stress, handlers should be trained in sheep and goat handling: Key aspects to be taught to handlers are the flight zone, flight distance and aspects of group herding, as well as leading animals with flags, avoiding moving the animals too fast and avoiding the use of sticks and electric prods. Also, sheep will be easier to handle if they are acclimatised to people walking through them (Grandin, 2014).

Since they tend to become stressed when cannot see each other, sheep must be handled in groups.

To avoid or limit handling, it is advised to kill animals in their home pen or close to it. When deciding on the killing methods to be applied, this should be taken into consideration.

In addition, staff fatigue is to be avoided and good rotation is to be ensured.

It is important to limit unexpected loud noises, because they lead to fear. The preventive measures will consist in education and training of staff to make them (i) aware that noise should be avoided and (ii) avoid shouting and making noise with the equipment and facilities and identify and eliminate the sources of noise.

Staff handling these animals should not be wearing yellow vests to prevent distractions.

Only trained dogs must be used to handle animals.

3.2.4 | Welfare consequence 'injuries': Assessment, hazard identification and management

Definition of 'Injuries'

The animal experiences negative affective states such as pain, discomfort or distress due to physical damage to somatic tissue types (bones, joints, skin, muscles).

ABMs for 'Injuries'

ABMs for injuries are presented and described in Table 7.

TABLE 7 ABMs for the assessment of injuries in sheep and goat during handling and moving.

ABM	Description
Skin lesions and wounds	Macroscopically visible loss of skin or underlying soft tissues integrity (adapted from Phytian et al., 2019)
Bone fractures	A fracture is a partial or complete break in the bone. Bone fractures are often caused by falls, trauma or as a result of a direct blow or kick to the body. Overuse or repetitive motions can cause stress fractures ¹⁷ .
Dislocated joints	A dislocation is a separation of two bones where they meet at a joint. This injury can temporarily deform and immobilise the joint

Hazards for 'injuries'

The main hazards that can lead to injuries during handling of sheep and goats are related to the facilities and to the handling by the staff.

Inadequate facilities:

If the handling facility is not well designed (e.g. 90° or lower angle of curvature in the raceways, ruptures or puddles in the floor surface, etc.) or constructed (slippery, etc.), this could lead to injuries when animals try to escape due to collisions with solid objects and sharp edges, till falling and slipping.

Inappropriate handling:

Inappropriate handling increases the risk of sheep and goats getting injured.

Prevention and correction of 'Injuries' and their related hazards

Facilities should be designed with solid-sided runs that allow several sheep to move together and not be distracted during handling and moving and should be designed without sharp projections, other injurious structures and slippery floors.

¹⁷<https://www.hopkinsmedicine.org/health/conditions-and-diseases/fractures#:~:text=points%20about%20fractures-,A%20fracture%20is%20a%20partial%20or%20complete%20break%20in%20the,motions%20can%20cause%20stress%20fractures.>

Raceways should be of sufficient height so that animals cannot jump or climb over them.

Premises with solid sides are better suited to handling goats and pen sides should be of a suitable height to prevent climbing. Curved passageways, rather than those with right angles, work well because lead animals can be seen by followers.

Handlers should be properly trained for handling and moving of sheep and goats (Grandin, 2014).

Animals that are lame, sick or injured have difficulties to walk by themselves and should only be moved when there is no other option and with enough support to avoid suffering. Preferably these animals should be killed in or close to their home pen. When it is necessary to move animals to a killing area, they should only be moved from their home pens to the killing pen/point and killed without any delay. They should be moved as calmly as possible and allowed to progress freely together. Animals should be handled quietly and without force.

3.2.5 | Outcome table on 'handling and moving' of sheep and goats

TABLE 8 Outcome table on 'Handling and moving'.

Hazard	Welfare consequence/s occurring to the animals due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure
Inadequate facilities	Restriction of movement, injuries	Staff, facilities	Inadequate preparation of the premises by staff; inappropriate lighting, distractions, improper construction (slippery floor, angles, open side raceways)	Ensure proper design, construction, ensure there are no distractions	Stop continuing movement of animals and take necessary action before resuming
People entering the pen/rearing area	Handling stress	Staff	Requirement for the process	None (unavoidable as part of the method)	Minimise disturbance
Inappropriate use of dogs	Handling stress	Staff	Staff employing un-trained dogs or losing the control of the dog	Avoid use of dogs when is not necessary and when sheep are not used to dogs or only use trained dogs	Stop the inappropriate use of dogs
Inappropriate handling	Handling stress, injuries	Staff, facilities	Lack of skilled operators, operator fatigue, lack of dedicated handling facilities, time pressure	Training of staff for proper handling; staff rotation, appropriate facilities to move animals (e.g. temporary passage or race ways)	Staff to act calmly, immediate shift of staff
Unexpected loud noise	Handling stress	Staff, facility, equipment	Staff shouting, machine noise, equipment noise, dog barking	Staff training, avoid personal shouting, do not operate noisy machines and equipment in the animal handling area	Identify and eliminate the source of noise, stop shouting

ABM: falling, slipping, trampling (restriction of movements), escape attempts, reluctance to move, vocalisations (handling stress), skin lesions and wounds, bone fractures, dislocated joints (injuries).

3.3 | Phase 1 (pre-killing): Restraint

Several killing methods are preceded by a restraint phase. 'Restraint' means the application to an animal of any procedure designed to restrict its movements in order to facilitate the subsequent killing.

Individual sheep and goat may be restrained manually or mechanically in order to present its head or body to the operator for the purpose of correct application of the method. Many killing methods require restraint of the animals (i.e. mechanical, electrical methods, lethal injection); however, some do not (i.e. firearms). In the next chapters, the different killing methods are described separately, and it will be specified whether they do or do not require restraint. However, sheep and goats can be stunned and killed in small groups, confined into a stunning pen, without individual restraint (e.g. electrical methods).

For application of captive bolt stunning, restraint is needed to ensure an accurate positioning and angle of the gun on the head. Similarly, for electrical methods, restraint is needed to ensure accurate positioning of the electrodes on the body. Also, the delivery of a blow to the forehead with a hard object requires the immobilisation of the animal and its head as well as lethal injection to access the jugular vein.

Independently of the specific killing method, the restraint before application of the method will already lead to some welfare consequences.

3.3.1 | The highly relevant welfare consequences identified for restraint

The results of the EKE exercise led to the identification of the highly relevant welfare consequences for restraint which are reported in [Table 9](#).

TABLE 9 Welfare consequences identified as most relevant for restraint.

Phase 1. Restraint

Welfare consequence

Restriction of movements

Handling stress

Soft tissue lesions and integument damage

Definition of 'Restriction of movements'

The animal experiences stress and/or negative affective states such as pain, fear, discomfort and/or frustration because it is unable to move freely or is unable to walk comfortably. Restriction of movements is a systematic welfare consequence for restraint, as it results from the application of the process itself.

Definition of 'Handling stress'

See Section [3.2.3](#).

Definition of 'Soft tissue lesions and integument damage'

The animal experiences negative affective states such as pain, discomfort and/or distress due to physical damage to the integument or underlying tissues, e.g. multiple scratches, open or scabbed wounds, bruises, ulcers, abscesses and hair loss (EFSA AHAW Panel, [2022](#)).

ABMs for 'Restriction of movements', 'Handling stress', 'Restriction of movements', 'Soft tissue lesions'

The ABMs for assessing each of the welfare consequences identified during restraint are presented together and described in [Table 10](#).

TABLE 10 ABMs for assessing welfare consequences identified during restraint and their description.

ABM	Description	Welfare consequence
Vocalisations	Bleating in goats and in lambs (Goldberg, 2018). This does not apply to adult sheep as they usually do not vocalise	Handling stress, restriction of movements, soft tissue lesions
Escape attempts	Attempts to go through, under or over gates and other barriers. Head and neck stretched forward and either held level with back or slightly raised above or below back line (extrapolated from cattle, from Lanier et al., 2001)	Handling stress, restriction of movements

TABLE 10 (Continued)

ABM	Description	Welfare consequence
Skin lesions and wounds	Macroscopically visible loss of skin or underlying tissues integrity (Phythian et al., 2019)	Soft tissue lesions
Facial expression	Tightening of facial muscles and related changes in the facial profile (Goldberg, 2018; Manteca et al., 2017). Changes in the facial expression of sheep can be measured using the Sheep Pain Facial Expression Scale (SPFES) elaborated by Mc Lennan et al. (2016)	Handling stress, restriction of movements, soft tissue lesions
Grinding of teeth (Bruxism)	Teeth grinding in sheep and goats (Goldberg, 2018; Manteca et al., 2017; Underwood et al., 2015) Sheep and goats in pain may grind together mandibular teeth with maxillary teeth	Handling stress, restriction of movements, soft tissue lesions
Curling of lips	Curling of upper lip in sheep (Goldberg, 2018; Manteca et al., 2017) Sheep and goats in pain may curl the upper lip, like flehmen	Handling stress, restriction of movements, soft tissue lesions

Hazards for restraint

Inappropriate restraint by humans (forceful)

If the operator uses severe force to restrain the animal for correct application of the stunning or killing method, the animal might experience welfare consequences such as handling stress, and soft tissue lesion and integument damage (see [Table 9](#) in Section 3.3.1).

Inadequate restraint by humans (too loose)

The operator may use a restraining technique that is not adequate to prevent the movement of the animal leading to inaccurate or interrupted application of the method (mechanical, electrical, lethal injection).

Preventive and corrective measures

Operators should be trained in restraining of sheep and goat e.g. regarding the understanding of the species-specific behaviours to prevent escape attempts.

Animals can be restrained mechanically to facilitate effective application of the method.

Duration of restraint should be as short as possible, and animals must be restrained only when operator and the equipment are ready to proceed to the stunning and killing procedures.

Equipment for restraint should be adjusted to the size of the animal category.

Strawbales or wooden boards available on the farm may be used to construct temporary 'stun boxes', crushes or narrow pens and to restrict movement of animals, if required. The height of these structures has to be adjusted according to the animal category. Goats have longer legs and narrower bodies than sheep, and therefore, restraints have to be adjusted appropriately. Head collar and lead rope, halter or bridle may be used to secure and to restrict movement of the head of animals. All halters, head collars and other equipment should be adjusted to the size of the animal.

3.3.2 | Outcome table for restraint

TABLE 11 Outcome table for restraint.

Hazard	Welfare consequence/s occurring to the animals due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/ (implementation of SOP)	Corrective measure
<u>Inappropriate restraint by humans (forceful)</u>	Restriction of movement, handling stress, wounds and soft tissue lesions	Staff, equipment	Staff using too much force and pressure Equipment inadequate to the size of the animals	Train the staff to not use force or pressure to restrain the animals Select appropriate equipment	Adjust the equipment Apply the stun or killing without delay
<u>Inadequate restraint by humans (too loose)</u>	Restriction of movement, Handling stress, wounds and soft tissue lesions	Staff, equipment	Staff using insufficient force Equipment inadequate to the size of the animals	Train the staff to use adequate force Reduce the pen size according to the group size to prevent animal moving around	Apply the stun or killing without delay

ABMs: Vocalisations (in goats and lambs), facial expression, grinding of teeth, curling of lips (handling stress, restriction of movements, soft tissue lesions), escape attempts (handling stress, restriction of movements), skin lesions and wounds (soft tissue lesions).

3.4 | Phase 2: The killing process

3.4.1 | 'Pain and fear' during the killing process

On-farm killing should cause loss of consciousness followed by death without causing avoidable pain or fear.

Pain is defined as an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage (Raja et al., 2020).

Fear is defined as an unpleasant emotional affective state induced by the perception of a danger or a potential danger that threaten the integrity of the animal (Boissy, 1995).

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 (Le Neindre et al., 2017).

In the context of killing, the assessment of consciousness is the state that matters, because it is the prerequisite to be able to experience any welfare consequence and negative affective states such as pain and fear.

The risk for an animal to be conscious after the application of a killing method is due to either an ineffective stunning or to the recovery of consciousness. Recovery of consciousness might occur in effectively stunned animals if the animals are not dead or when an additional killing method is not performed without delay or was not properly done.

In this context, indicators of consciousness are the ABMs that are assessed to evaluate if animals are conscious and therein exposed to negative affective states such as pain and fear. Indicators of consciousness are specific for each stunning method (EFSA, 2004, 2006; Comin et al., 2023 for sheep) and will be presented separately for each method in the next sections.

ABMs related to consciousness were described in a previous EFSA Opinion (EFSA AHAW Panel, 2013a), which reported a toolbox for several stunning methods. The use of these indicators is also reviewed in a recent publication (Tetlow et al., 2022) in terms of feasibility.

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

Death should always be monitored and confirmed after applying the killing method and before disposal of the carcasses. Section 3.4.9 addresses the risk of disposing animals while being alive.

3.4.2 | Methods used to kill sheep and goats

The main on-farm killing methods of sheep and goats are grouped into electrical, mechanical and lethal injection.

The methods, including the welfare consequences, animal-based measures, related hazards and preventive and corrective measures, are described in the following Sections 3.4.3–3.4.8; the outcome table related to each method is reported in each relevant section.

For any method, the interval between stunning and killing (by bleeding, pithing or induction of cardiac arrest) should be as short as possible to prevent recovery of consciousness. If consciousness is detected after stunning, an appropriate back-up method should be applied without any delay followed by the application of a killing procedure.

The effectiveness of a killing should be monitored immediately after application and death should be confirmed before carcass disposal.

3.4.3 | Electrical killing methods

Two kinds of electrical killing methods are used at present: the two-cycle method with head-only electrical stunning followed by the induction of ventricular fibrillation and the one-cycle method of head-to-body application of an electric current (electrocution).

Effectiveness of stunning/killing with currents lower than 1A was tested in experimental conditions by Llonch et al. (2015). The authors concluded that both head-only and head-to-body electrical stunning with currents of 0.3, 0.5 and 0.7 A induce effective stunning similar to 1.0 A in lambs up to 16 kg and kid goats up to 7 kg live weight. After stunning, all animals showed tonic-clonic muscular activity and epileptiform EEG, and absence of rhythmic breathing, corneal reflex, spontaneous blinking and pain sensibility. The duration of unconsciousness was also similar among the different treatments.

Sanchez-Barrera et al. (2014) demonstrated using power spectral analysis of the EEG that head-only electrical stunning of 10-week-old lambs ($n=30$) with 0.9A delivered using 250V for 6s produced epileptic activity in the brain.

Even though currents lower than 1A were found to be effective in stunning lambs and goat kids under laboratory conditions, practical limitations exist under field conditions (e.g. not ensuring correct placement of the electrodes) that affect effectiveness of the method (EFSA AHAW Panel, 2013b, 2015), and therefore as a precaution at least 1A should be used to ensure effectiveness.

Two-current-cycle method

Two-step electrical killing involves application of head-only electrical stunning by placing two electrodes on either side of the head to span the brain followed, without any delay, by application of a second current cycle across the chest to span the

heart. Both the current cycles are applied using a 50-Hz sine wave alternating current, which is more effective in stunning and killing by inducing cardiac arrest. A minimum current of 1.0 A should be applied for a minimum of 2 s across the head and 3 s across the chest (European Commission, 2017). A minimum of 150 V is required to deliver this amount of current.

First, the operator is applying head-only electrical stunning that is based on the principle of passing an electric current of enough magnitude through the brain of the animal that induces a generalised epilepsy (see for details EFSA, 2004). The stunning tongs or electrodes are placed between the outer corners of the eyes and the base of the ears on either side of the head (Figure 1). If fleece cover or presence of horns hinder placement of electrodes on the ideal position on the head, which is on the temporal bones on either side of the head that is known to offer least electrical resistance to current flow, then a different electrode position may be selected. In this regard, the head-only electrical stunning tongs/electrodes may be placed on different locations on the head such that they always span the brain.



FIGURE 1 Illustration of the application of the current to the head to render the animal unconscious (first cycle of electrical killing for sheep and goats) (European Commission, 2017).

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, animals show tonic seizure followed by clonic seizures, indicative of generalised epilepsy. Typically, during the tonic phase, animals are in a state of tetanus and stretch out their fore- and hind-legs under the belly, breathing is absent, and the eyeballs are fixed or rotated into the socket (Figure 3; European Commission, 2017). The tonic phase is followed by the clonic phase, which manifests with kicking of legs, paddling or galloping movements (EFSA AHAW Panel, 2013a; Gregory, 1998; Velarde et al., 2000). 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 reflexes and response to painful stimuli (EFSA AHAW Panel, 2013a).

Evaluation of electrical stunning practices used in sheep slaughterhouses in the UK and the effectiveness of the stun showed that the stunning tongs were placed around the head in several positions, spanning the brain and the effectiveness varied according to the position (Figure 2; Laws-Smith, 2014).

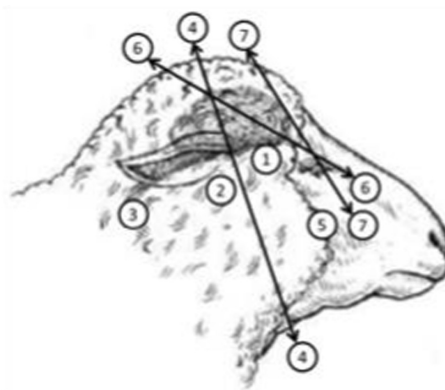


FIGURE 2 Electrical stunning tong positions evaluated by Laws-Smith (2014).

In this illustration, position 1: between the eye and the base of the ear on each side of the head; position 2: below the base of the ear on each side of the head; position 3: across the neck, behind the ears; position 4: placement of one electrode on top of the head and the other under the head; position 5: on the nose/jaw; position 6: placement of one electrode behind the ear and the other on the nose; position 7: placement of one electrode between the eye and the base of the ear and the other on the nose.

In this study, the extent of wool covering the electrode placement sites was also scored as shown in Figure 3.

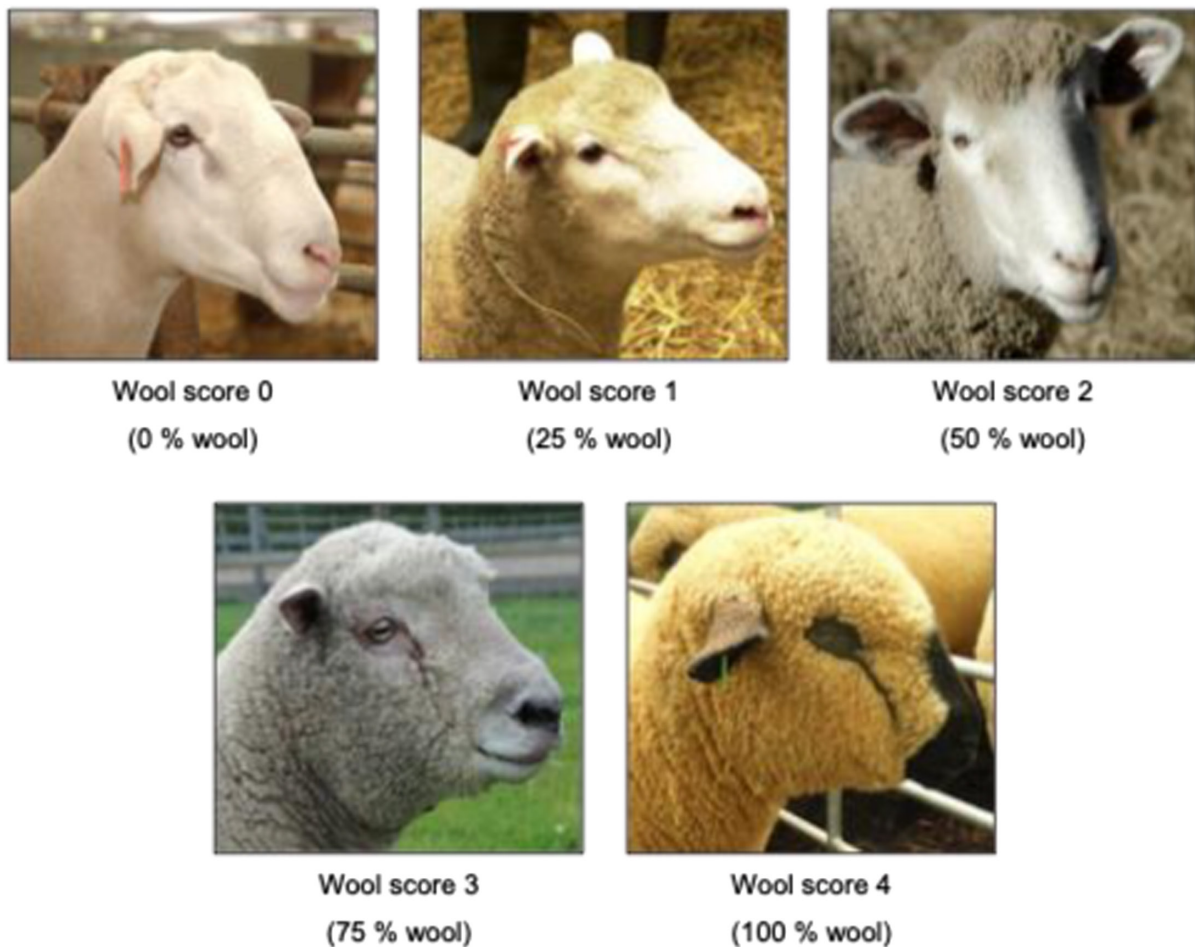


FIGURE 3 The scoring system used to by Laws-Smith (2014) to assess and record the amount of wool present in the sites of application of the electrodes.

The ABMs used by Laws-Smith (2014) at slaughter to assess unconsciousness just after stunning were the presence of a tonic seizure, immediate collapse, the absence of righting reflex, the absence of vocalisations and the absence of rhythmic breathing. The ABMs used to assess and record immediately before and during hoisting were the presence of a tonic-clonic seizure, the absence of righting reflex, the absence of vocalisations and the absence of rhythmic breathing. The ABMs used to assess and record immediately before and during bleeding were the absence of righting reflex, the absence of vocalisations and the absence of rhythmic breathing.

The study of Laws-Smith (2014) aimed to assess whether variations in electrode positions can have an impact on the effectiveness of the stun, as well as whether the amount of wool present in the application sites of the electrodes can have an impact. The study found that in one abattoir the electrode position had a significant impact ($p < 0.05$) on the effectiveness of stun, with it being least effective when electrodes were applied in a position that was not spanning brain, but the amount of wool did not have any significant impact. The results show that the stun was most effective when the electrodes were applied in position 6, and that the effectiveness of the stun decreased when the electrodes were applied in positions 7, 2, 1 and 5, in decreasing order. The effectiveness of the stun was, nevertheless, only found to be significantly different between the means of electrode positions 1 and 5. Lacking information for goats, the EFSA experts assumed that also in goats the electrode position spanning the brain is effectively inducing unconsciousness.

Effectively stunned animals might recover consciousness rapidly and it begins with the resumption of spontaneous breathing. In an experiment on lambs from Velarde et al. (2002), animals recovered breathing on average 29.5 ± 1.55 s after stunning and this was 6.9 ± 1.32 s before the end of the first clonic phase. Animals will then 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.

During killing of sheep and goats using two-current cycles 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 a second current cycle across the chest, behind the elbow joint, to induce cardiac ventricular fibrillation (Figure 4). Alternatively, the electrodes can be placed one on the middle of the chest on the brisket and one on the back of the animal so as to span the heart. Unconsciousness must be confirmed in animals before the application of cardiac arrest current cycle. In addition, 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.

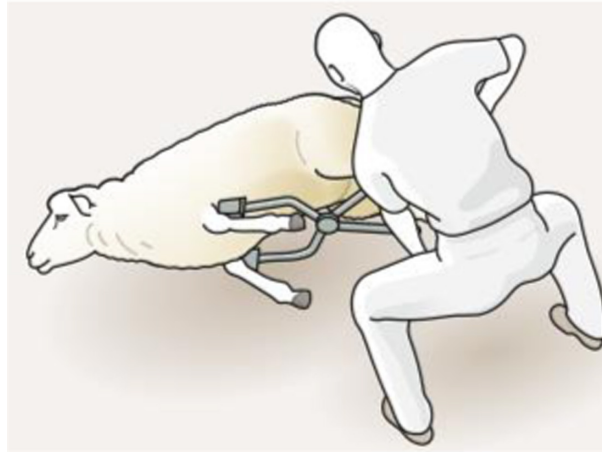


FIGURE 4 Illustration of the application of cardiac arrest current (second cycle) in sheep and goats rendered unconscious first by head-only electrical stunning (European Commission, 2017).

In case bleeding is a preferred option rather than chest current application, it should be ideally performed during tonic phase by severing both the carotid arteries or brachiocephalic trunk. If lethal injection is preferred, it should be administered without delay in unconscious animals.

One-current cycle method (head-to body or electrocution)

In head-to-body electrical killing (electrocution) using a single current cycle, the front electrode is placed on the head to span the brain and the rear electrode is placed on the chest behind the position of the heart to induce cardiac ventricular fibrillation (Figure 5; HSA, 2016).



FIGURE 5 Illustration of head-to-body electrical stunning of sheep with one-current cycle (HSA, 2016).

Effective head-to-body electrical stunning is characterised by tonic seizure during exposure to the stunning method. After exposure, animals may have 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). Death should always be confirmed before carcass disposal.

Mason et al. (2018) demonstrated in anaesthetised lambs ($n = 3$; live weight 25–39 kg) that, using a pair of modified electrodes, passing a 50-Hz electric current from top of the head to the sternum at 1.5A for 3.1 s resulted in epileptic activity followed by isoelectric activity in the EEG indicative of brain death and successful induction of cardiac ventricular fibrillation using electrocardiogram (ECG).

3.4.3.1 | Hazard identification for 'electrical methods'

To avoid as much as possible pain and fear, animals are rendered unconscious as soon as possible in the process and in any case before application of the killing method. Therefore, and as explained in Section 3.4.1, hazards leading to persistence of consciousness in animals are to be identified, since consciousness is a prerequisite to experience negative affective states such as pain and fear. These hazards are:

1. Wrong placement of the electrodes
2. Poor electrical contact
3. Too short exposure time
4. Inappropriate electrical parameters
5. Disposal of animals while alive

Wrong placement of the electrodes

The position of the head electrodes does not span the brain to induce immediate unconsciousness, or the second current cycle applied across the chest to induce cardiac arrest in unconscious animals does not span the heart. It has been reported that placement of electrodes on the cheek or nose is ineffective as the electrodes do not span the brain to induce unconsciousness.

If the head electrode is allowed to slide back onto the neck, the electrodes do not span the brain to induce unconsciousness. This could lead to painful induction of cardiac arrest in conscious animals.

Electrical killing of sheep and goats individually can be carried out without restraint by confining a small group of them in a pen, but this procedure may be prone to operator error, as accidental pre-stun electric shocks may be delivered to adjacent animals due to slipping of the electrodes.

Furthermore, the presence of other animals in the pen can also constitute a hazard leading to the wrong placement of the electrodes. If the animals are stunned in groups, sheep may keep their heads low or under other animals in the group, which will impede accurate placement of electrical stunning tongs.

Poor electrical contact

The electric contact between the animal and stunning electrodes is not sufficient to facilitate current flow necessary to achieve immediate unconsciousness or cardiac fibrillation. Good electrical contact with the skin may be difficult due to the density and/or length of hair/fleece (European Commission, 2017). Electrical contact on the animal may be interrupted by movement of the animals due to lack of or inappropriate restraint, leading to ineffective stunning causing pain and fear.

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. In unrestrained animals, the contact between the stunning electrodes and the animal may be lost due to movement of the animal when in a group, or to the fact that the initial current flow causes the immediate collapse of the animal and the operator fail to maintain continuous electrical contact (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. 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 and lack of adjustment to the settings to suit different animal types. The thickness of fleece covering the head can affect the resistance to current flow, for example, sheep with light and heavy fleece covers have, respectively, an electrical resistance of 150–400 and 150–1000 Ohms at the site of electrode positions (HSA, 2016). When a constant voltage is used to stun, animals with heavy fleece cover would receive very low current and be prone to ineffective stunning.

Also, while a 50-Hz sine wave alternating current is effective in inducing cardiac ventricular fibrillation leading to cardiac arrest, the use of high frequencies is not effective (EFSA, 2004), any current higher than 50 Hz increases the likelihood of failure in killing the animal.

3.4.3.2 | Animal-based measures (ABMs) in the context of electrical killing

As explained in Section 3.3.3.1, the ABMs to be assessed during electrical killing are those reflecting consciousness, which is a prerequisite for animals to experience pain and fear.

After the killing process, animals should be dead, and any outcome of life will be interpreted as a possibility for animals to recover consciousness and then be able to experience pain and fear. Therefore, ABMs of both, state of consciousness and state of death, are used to assess pain and fear in these specific conditions.

For head-only electrical stunning, in a previous EFSA opinion (EFSA AHAW Panel, 2013a), a series of ABMs for the state of consciousness were selected to monitor the sheep and goat slaughter process. The same ABMs were retrieved in the literature considered in this opinion (for a review, see Comin et al., 2023) and are therefore proposed to be used also to monitor the state of consciousness and subsequently the state of death during on-farm electrical killing.

For the assessment of the state of consciousness, the identified ABMs are posture, breathing, tonic/clonic seizures, corneal or palpebral reflex, vocalisation and eyes movements. For the assessment of the state of death after the electrical application to the cardiac region, the recommended ABMs are body movements, breathing, corneal or palpebral reflex, heartbeat and pupil size. These ABMs (e.g. breathing) are phrased so that their corresponding outcomes will indicate either unconsciousness and the absence of pain and fear (e.g. apnoea) or consciousness and the risk of pain and fear (e.g. rhythmic breathing).

The same rationale applies for the ABMs of the state of death and their corresponding outcomes of life and death.

In case of a one cycle of head-to-body application, death is induced by cardiac fibrillation and should be assessed through the ABMs of the state of death.

For details, the ABMs for the state consciousness and of death and their corresponding outcomes are described in full in Table 12.

TABLE 12 ABMs for assessment of 'State of consciousness' after electrical stunning.

ABMs	Description of the corresponding outcomes
State of consciousness	
Posture	Effective stunning will result in immediate collapse or loss of posture. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse (EFSA AHAW Panel, 2013a)
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, 2013a)
Tonic-clonic seizures	Effective stunning leads to the onset of tonic-clonic seizures soon after collapse, which may be recognised from the tetanus. The tonic seizure lasts for several seconds and is followed by clonic seizures lasting for seconds and followed by loss of muscle tone Ineffectively stunned sheep and goat fail to show tonic-clonic seizure and may show only tetanus during the flow of the current through the body (EFSA AHAW Panel, 2013a)
Palpebral and/or corneal reflex	The palpebral reflex is elicited by touching or tapping a finger on the inner/outer eye canthus or eyelashes. Effectively 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, 2013a)
Vocalisations	Conscious animals may vocalise, and therefore 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, 2013a)
Eye movements	Eye movements and the position of the eyeball can be recognised from close examination 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, 2013a)
State of death	
Body movements	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, 2013a)
Breathing	Irreversible absence of breathing is a sign of death (EFSA AHAW Panel, 2013a)
Corneal or palpebral reflex	Irreversible absence of response to palpebral and corneal stimuli is a sign of death (EFSA AHAW Panel, 2013a)
Heartbeat	Absence of heartbeat is a sign of death (EFSA AHAW Panel, 2013a)
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, 2013a)

These ABMs were therefore included in the following flowchart (Figure 6), including toolboxes of ABMs (blue box in the figure) to be used during on-farm killing. For each ABM, there are corresponding outcomes of consciousness and unconsciousness as well as corresponding outcomes of life and death. The indicators are not ranked based on sensitivity and

specificity. In the review of Comin et al. (2023), different methods assessing each recommended ABMs can be found for sheep. It is also possible to use them in goats. In case sheep or goat show any of the outcomes of consciousness then an intervention should be applied (i.e. a back-up method). After any reintervention, the monitoring of the state of consciousness, according to the flowchart, should be performed again. Only when the corresponding outcomes of unconsciousness are observed the process can continue to Step 2 (cardiac application).

Following Step 2, in case sheep and goat show any of the outcomes of life, an intervention should be applied. If outcomes of death are observed the animals can be processed further (disposal of animals).

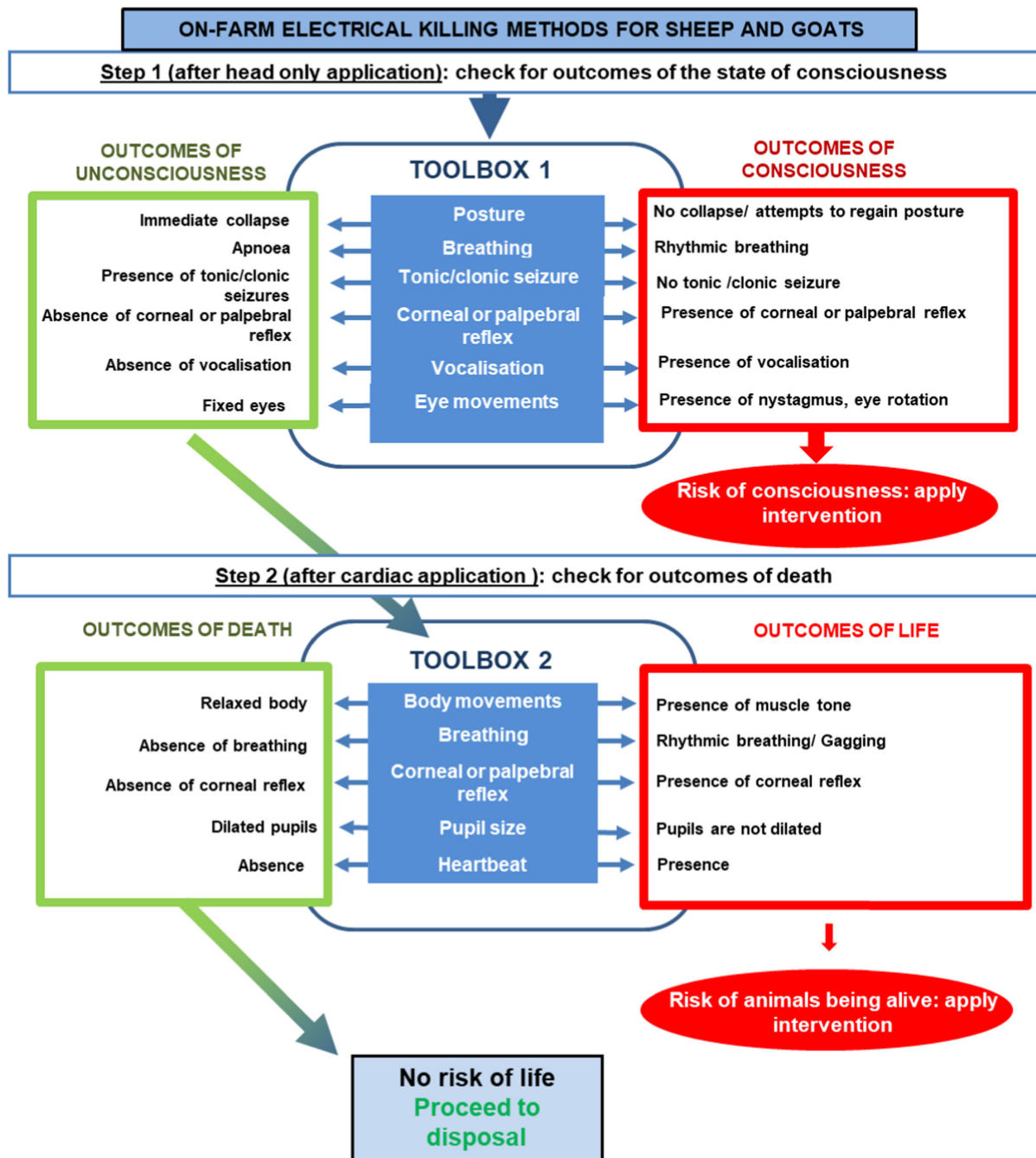


FIGURE 6 Flowchart including indicators for the monitoring of state of consciousness and death when using on-farm electrical killing methods.

3.4.3.3 | Prevention and correction of welfare consequences and their related hazards during electrical stunning

To prevent any hazard leading to consciousness during application of head-only electrical stunning the equipment should have the adequate design, construction and maintenance and staff should be trained and competent. Possible movements of the animal should be restricted e.g. in a small 'stun box' to facilitate correct application of the stunning and killing method; in case this is not successful, the animal should be properly restrained by the operator.

Strawbales or wooden boards available on the farm may be used to construct temporary 'stun boxes' and restrict movement of animals, if required, during the application of stunning. Hand-held stunning tongs can be applied without

separating the animals from the group and by only limiting the movement of the animals in a restricted area to prevent the animals from turning or moving away.

The stunner should be equipped with a built-in timer monitoring exposure time or visual or auditory warning system to alert the operator of success or failure of the process.

Staff should be trained to acquire adequate knowledge and skills to understand the behaviour of sheep and goats and the need for the optimal method to restrict animal movements required for stunning and killing.

Staff should be trained for correct placement of the stunning or killing electrodes, maintaining adequate pressure, continuous contact between the animal and electrodes. The operator should also have adequate knowledge, understanding and skills to recognise any variable (e.g. variation in the size of animal, accumulation of grease, wool, hair or dirt around the electrode contact area on the animal or build-up of dirt on the electrodes, malfunctioning of equipment) leading to wrong placement of electrodes or insufficient flow of current. Staff should be trained to minimise the fear inflicted to sheep so to reduce the risk of one sheep hiding below another. The operators need to assess the amount of fleece cover, i.e. density and/or length of fleece covering the electrode position and choose electrical tongs/electrodes with long enough pins to penetrate the fleece in order to make contact with the skin and apply enough pressure during the current application to maintain good electrical contact. Slowing down the process will help to prevent or minimise the incidence of some of the hazards. Regular cleaning of electrodes using a wire brush, calibration and maintenance of the equipment is essential to prevent hazards that might lead to ineffective stunning and killing.

Inadequate head-only 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 checks on the effectiveness of killing by assessing the 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.

Several factors influence the welfare outcomes of electrical stunning (European Commission, 2017): (i) the sheep's wool and goats' hair should be entirely dry; if they are wet, the electricity may flow (shunt) through the wet wool or hair rather than through the brain or body; (ii) good placement of the tongs can be difficult on animals with horns and on sheep with woolly heads; (iii) using electrodes with pins or with wet pins for woolly animals would help to overcome the problem; (iv) alternatively, one can remove wool from the area where the electrodes will be positioned on the animal; (v) wetting the application area with water (especially salted water) can also increase electrical contact; (vi) ensure the tongs are the correct size for the animal; (vii) ensure the tongs are not corroded and keep them clean at all times; (viii) there should not be any delay between the electrode placement on the animal and switching on the electric current. Some animals, especially goats, may be very active and may require individual restraining to enable good positioning of the tongs.

3.4.3.4 | Outcome table on 'electrical killing'

TABLE 13 Outcome table on 'Electrical killing' (one or two cycle methods).

Hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Wrong placement of the electrodes	Staff, equipment	Too fast operation, equipment does not suit the size of animals Lack of skilled operator Improper or lack of restraint Presence of other animals in the pen	Staff training Appropriate restraint Choose the right size equipment Slow down the process	Stun using correct placement or use a back-up killing method
Poor electrical contact	Staff, equipment	Lack of skilled operators, staff fatigue; incorrect placement of the electrodes; poorly designed, constructed and maintained equipment; intermittent contact Heavy wool cover or excessive soiling	Staff training; staff rotation; ensure correct presentation of the animals, ensure correct maintenance of the equipment; shear or clip the wool cover; ensure the equipment includes electrodes for different sized animals; ensure continuous contact between the electrodes and the animal; ensure regular calibration of equipment, regular cleaning of the electrode with a wire brush	Stun the animal correctly or use a back-up killing method
Too short exposure time	Staff	Lack of skilled operators, too fast operation	Staff training Slow down the process 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 back-up killing method
Inappropriate electrical parameters	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	Only use 50–60 Hz frequency sine wave alternating current, ensure the voltage is sufficient to deliver minimum current; regular calibration and maintenance/cleaning 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 back-up killing method
Delayed application of killing cycle	Staff	Lack of skilled operators, lack of monitoring,	Ensure staff training and apply the killing procedure without any delay after stunning	Re-stun the animal and apply the killing without delay

ABMs:

Posture, breathing, tonic-clonic seizures, palpebral and/or corneal reflex, vocalisations, eye movements (state of consciousness).

Body movements, breathing, corneal or palpebral reflex, heartbeat, pupil size (state of death).

3.4.4 | Penetrative captive bolt stunning followed by a killing method

Penetrative captive bolt (PCB) powered by cartridge is the most commonly used method to stun sheep and goats. The method is usually applied on restrained animals. The gun powder content (strength) of the cartridge should be selected according to the manufacturers' instructions to suit the animal type. 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 and immediate loss of consciousness (EFSA, 2004). Penetration of the bolt into the skull and subsequent withdrawal causes structural damage to the brain due to cavitation, which results in marked subarachnoid and intraventricular haemorrhages, especially adjacent to the entry wound and at the base of the brain. The bolt diameter, velocity and penetration depth are important parameters to ensure efficacy of the stun. It causes subsequent disruption of the brain tissue and helps to prolong the duration of unconsciousness and insensibility (EFSA, 2004). Some guns have a captive bolt that protrudes from the muzzle when it is in the primed position and others have a bolt that is recessed within the muzzle. Normally, when a bolt is fired, it requires a short distance to reach its maximum velocity before impacting on the skull. Therefore, guns with protruding bolts should be held slightly (up to 5 mm) away from the animal's head, whereas guns with recessed bolts must always be pressed firmly against the head. Various factors such as anatomical differences due to breed, sex or age of the animal, choice of the captive bolt gun and its maintenance, cartridge strength and its condition, shooting position and type of restraint used determine the effectiveness of stun. Death may occur depending on the degree of injury to the brain but is not a guaranteed outcome (Lambooy & Algers, 2016). Therefore, captive bolt stunning shall be followed as quickly as possible (as a guidance, within 16 second after shooting, according to EFSA (EFSA, 2004) by a killing action like pithing or bleeding).

Sheep and goats have extremely variable skull morphology particularly with regard to the presence, size and internal complexity of the frontal sinuses (AWC, 2020). These are air-filled paranasal spaces, located within the expanded frontal sinuses which occasionally extends up into the horncores (Farke, 2010). It has been suggested that the enlarged frontal sinuses of horned sheep and goats may be an adaptation for head-to-head combat and that these structures may have a shock absorbing function – protecting the brain from impacts to the horns (Farke, 2008). The sinuses are defined by two layers of cortical bone: one at the outer table of the skull (the 'external cortex') and one forming part of the surface of the endocranial cavity ('internal cortex'). Bony struts (usually numbering between four and six on each side in goats, with a typical thickness of 1 mm or less) may divide the sinuses into a series of interconnected chambers. Comparative morphological analysis suggests that relative frontal sinus size and complexity, as well as ramming behaviour, has a strong phylogenetic component (Farke, 2010), meaning breed differences in these two species. Both sheep and goats have an extensive frontal sinus that occupies the entire frontal bone, but the sinuses are less prominently strutted in goats compared to sheep (Farke, 2010). Particularly in older males and horned goats, the sinuses may absorb the energy from a non-penetrative captive bolt device or reduce the depth of penetration of the bolt into the brain when a penetrative captive bolt stunning device is deployed. Both could result in reduced effectiveness of the stun. Collins et al. (2017) demonstrated using adult goat cadavers and assessment of the effects of firing penetrating captive bolt using gross pathology and CT and MRI scans that PCB can be effectively used to induce brain trauma potentially sufficient to result in stunning and unconsciousness of live goats. Plummer et al. (2018) evaluated the use of penetrative captive bolt (Cash Special captive bolt pistol, 0.25 calibre yellow cartridge; Accles and Shelvoke Ltd, Sutton Coldfield, West Midlands, England) in adult goat cadaver and anaesthetised goats. The shooting position used in this study was as recommended by AVMA (2016) as presented in Figure 7. The results of this study showed consistent disruption of the midbrain and thalamus in all goats. Immediate cessation of breathing followed by a loss of heartbeat in all 10 of the anaesthetised goats.

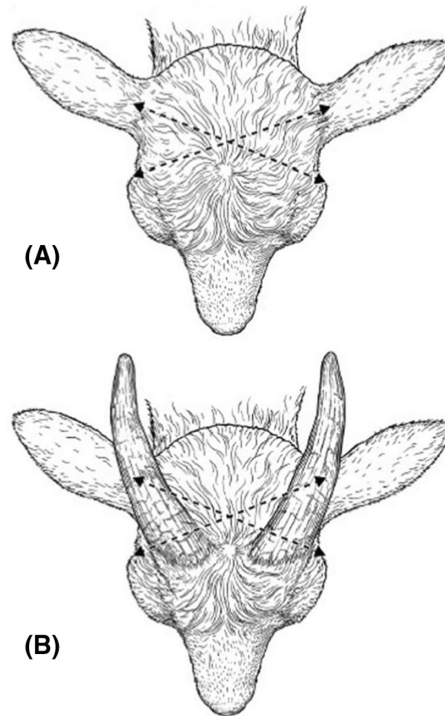


FIGURE 7 Schematic depictions of the method for determining the proper anatomic site for killing of a polled goat (A) and horned goat (B) by use of a firearm or captive bolt device (AVMA, 2016).

The ideal shooting position varies depending on whether the animal is polled (hornless) or horned. For polled sheep, the captive bolt should be fired on the highest point of the head, and on the midline, aiming straight down. When frontal shooting position is preferred, the shooting position is at the intersection of two lines, drawn from the lateral canthus of the eye to the middle of the base of the opposite ear (Figure 8; HSA, 2017).

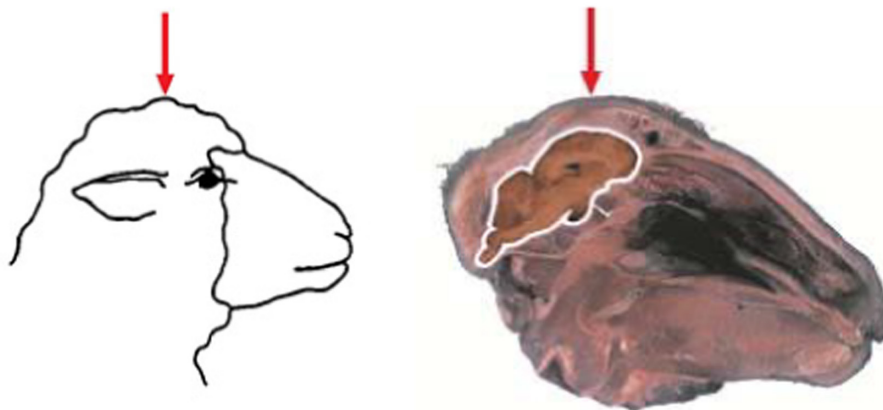


FIGURE 8 Ideal captive bolt shooting position for polled sheep (HSA, 2017).

For horned sheep and goats, the muzzle of the stunner should be placed on the midline, behind the ridge between the horns and aimed towards the base of the tongue (Figure 9; HSA, 2017).



FIGURE 9 Ideal captive bolt shooting position for horned sheep and goats (HSA, 2017).

The Humane Slaughter Association (HSA, 2017) advises that for captive bolt stunning of all goats, the bolt should be placed behind the bony mass on the midline and aimed towards the base of the tongue, irrespective of whether they have horns or not (Figure 10). Collins et al. (2017) also suggested a shot position slightly more caudal (back of the head) would be effective.

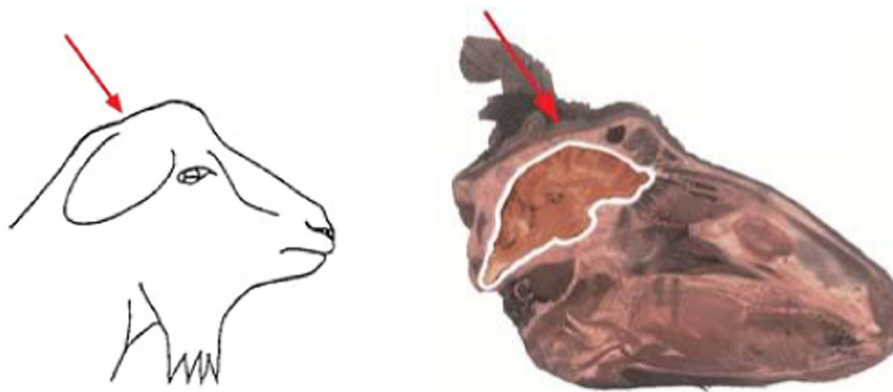


FIGURE 10 Ideal captive bolt shooting position for goats (HSA, 2017).

According to the AVMA euthanasia guidelines (AVMA, 2020; Figure 11), for polled sheep or goats (A), penetrative captive bolt should be placed perpendicular to the skull over the anatomic site identified as slightly caudal to the poll (the crown or the highest point on the head) at the intersection of two lines drawn from the outside corner of each eye to the middle of the base of the opposite ear. Alternatively, a site located on the dorsal midline of the head, which corresponds with the external occipital protuberance of the skull, may be used. When using the site associated with the external occipital protuberance, the PCB should be placed flush with the skull at the external occipital protuberance while angling or aiming the muzzle of the PCB towards the mouth. Panel B indicates direction of the shot (based on observations in goats by Collins et al., 2017 and Plummer et al., 2018).

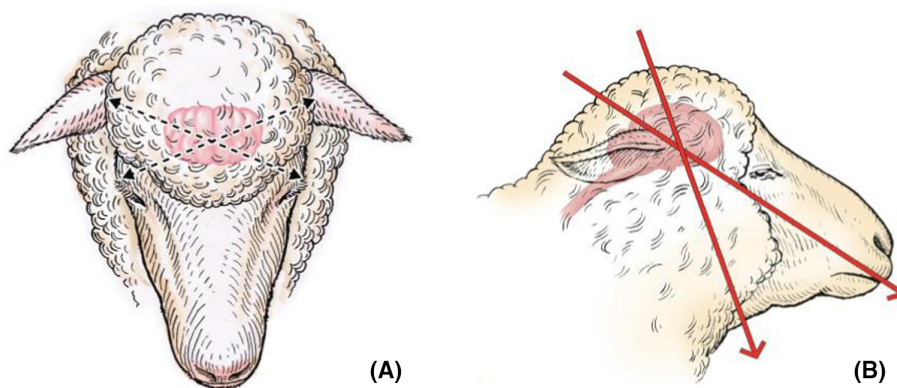


FIGURE 11 Penetrative captive bolt shooting position for polled sheep and goats (AVMA, 2020). Black arrows (A) indicate the shooting point based on the intersection of two lines drawn from the outside corner of each eye to the middle of the base of the opposite ear. Red arrows indicate the angle that can be used for the shot.

According to the AVMA guidelines (AVMA, 2020; Figure 12), for horned sheep or goats (A), PCB should be placed perpendicular to the skull over the anatomic site identified as slightly caudal to the poll (also known as the crown or the highest point on the head) at the intersection of two lines drawn from the outside corner of each eye to the middle of the base of the opposite ear (based on observation by Plummer et al., 2018). Alternatively, a site located on the dorsal midline of the head, which corresponds with the external occipital protuberance of the skull, may be used. When using the site associated with the external occipital protuberance, PCB should be placed flush with the skull at the external occipital protuberance while angling or aiming the muzzle of the PCB towards the mouth (based on Collins et al., 2017). Panel B indicates direction of shooting.

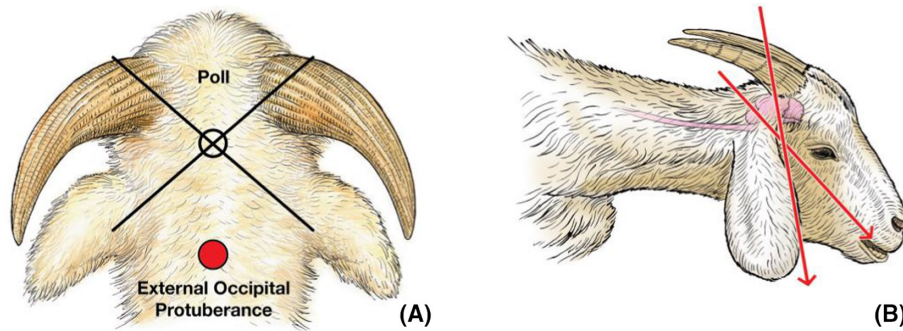


FIGURE 12 Penetrative captive bolt shooting position for horned sheep and goats (AVMA, 2020). Black arrows (A) indicate the shooting point based on the intersection of two lines drawn from the outside corner of each eye to the middle of the base of the opposite ear. Red arrows indicate the angle that can be used for the shot.

In the event where penetrative captive bolt stunning is not effective in producing death, it should be followed, without any delay, by a secondary killing procedure such as pithing, bleeding or lethal injection. Intravenous administration of an anaesthetic drug or saturated solution of potassium chloride may be used (AVMA, 2020).

3.4.4.1 | Hazard identification for 'Penetrative captive bolt'

The hazards identified during this process are:

About stunning method:

1. Incorrect position and direction of the shot
2. Incorrect captive bolt parameters
3. Overheating of the captive bolt gun

About the killing method:

4. Prolonged stun to kill interval
5. Incomplete sectioning of the blood vessel
6. Ineffective pithing
7. Sublethal dose of chemical

Incorrect position and direction of the shot

Firing captive bolts in incorrect position or in the wrong direction can result in ineffective stunning leading to persistence of consciousness and therefore the animal able to experience pain and fear.

Gibson et al. (2012) investigated in detail the pathophysiology of penetrative captive bolt gun injuries that result in incomplete concussion leading to death in horned and polled sheep. In this study, polled ewes and rams were shot on midline at the highest point on the head while aiming towards the base of the tongue. Horned ewes and rams were shot on midline between the base of the horns just caudal to the nuchal crest while aiming towards the back of the throat. The animals were shot once, with either the industry recommended gun/cartridge combinations or with higher powered combinations after the failure to induce irrecoverable concussion leading to death.

Immediately after shooting, all the animals were observed for clinical signs of insensibility and/or return of sensibility, including the presence or absence of immediate collapse, righting reflex, rhythmic breathing, jaw muscle tension, heartbeat (palpation of the chest), corneal reflex, palpebral reflex, eyeball rotation, pupil dilatation, nystagmus and leg kicking. The heads of dead animals were also removed and band-sawed longitudinally through or near to the bolt penetration site. The trajectory and penetration depth of the bolt was measured from the outer surface of the head using a plastic probe inserted through the

bolt entrance cavity. Shots were divided as being either correctly or incorrectly placed based on trajectory. Correctly placed shots were where the bolt entered on or near to the aimed shooting position, without excessive lateral/rostral/caudal angulation, damaging the cerebrum, cerebellum and brainstem. Incorrectly placed shots were where the bolt either missed the brain or entered off midline, angling excessively (laterally/rostrally/caudally) and missing or superficially damaging the parietal, occipital lobes, cerebellum and completely missing the brainstem. Brains were examined for gross lesions, displacement of tissue (extrusion of tissue out of the bolt cavity and cerebellar coning), haemorrhage and position of bone fragments. The skull was examined for bone and skin tissue thicknesses and signs of cavitation of the inner table of the cranial vault at the bolt entrance site. Severity of tissue damage of specific brain regions and brain haemorrhage was assessed subjectively.

The results indicated that, out of 489 sheep, rams (10%) were more likely to show signs of incomplete concussion than ewes (2%), and horned animals (8%) more likely than polled (3%). Sixteen percent of horned rams had signs of incomplete concussion. Inaccuracy of the shot assessed during post-mortem examination was associated with incomplete concussion: 100% of animals that showed signs of incomplete concussion were found to have been shot incorrectly. Seventy-nine percent of incomplete concussion cases were associated with the bolt missing the brain entirely. Bad marksmanship (37%) and cases where the bolt missed the brain (15%) were more common in horned rams than polled rams and ewes (horned and polled) due to the position of the shot and the characteristics of the animal head.

In addition, the average bolt penetration depth in the head was largest in polled rams (71 mm) and lowest in polled ewes (66 mm). Rams (horned 12 and polled 11 mm) had significantly thicker skulls than ewes (horned 7 and polled 8 mm) and had a thicker skin tissue pad above the skull at the site of bolt penetration. The skin tissue pad was 5, 7, 16 and 21 mm thick in polled ewes, horned ewes, polled rams and horned rams, respectively.

The presence of other animals in the pen can also constitute a hazard leading to the incorrect position and direction of the shot. If the animals are stunned in groups, sheep may keep their heads low or under other animals in the group, which will impede the accuracy of the shot.

Incorrect captive bolt parameters

This hazard can lead to pain and fear because it can lead to failure in onset of unconsciousness or to recovery of consciousness before a killing method is applied (EFSA AHAW Panel, 2013a, 2021).

Overheating of the captive bolt gun

Repeated firing of a captive bolt in quick succession will lead to overheating of its barrel and, as a consequence, it will be difficult to hold and apply correctly, or the gun will cease to function properly. Therefore, captive bolt guns should be rested to cool and there should be enough guns available on site for this rotation to occur.

Prolonged stun to kill interval

The interval between captive bolt stunning and application of a killing procedure (i.e. intravenous injection of saturated solution of potassium chloride or overdose of anaesthetic drug, pithing or bleeding) is long enough for sheep and goats to recover consciousness and experience pain and fear.

Incomplete sectioning of the blood vessel

Failure to completely cut the carotid arteries or the brachiocephalic trunk that gives rise to carotid arteries will maintain blood supply to the brain and therefore can lead to recovery of consciousness or delayed onset of death. It is worth noting that the prevalence of ballooning of the severed carotid arteries due to the formation of false aneurism in lamb is reported to be nil (Gregory et al., 2006). Therefore, cutting the brachiocephalic trunk may not be necessary in sheep.

Ineffective pithing

Pithing applied as a killing procedure is ineffective and fails to destroy the brainstem and upper spinal cord leading to recovery of consciousness. This might occur when the rod is not long enough to destroy these areas of the brain or the direction of the movement with the rod does not target the deeper parts of the brain.

Sublethal dose of chemical

The dose administered as a secondary procedure is not adequate or inappropriate route of administration to kill the animal, leading to recovery of consciousness or animals remaining alive.

3.4.4.2 | *Animal-based measures (ABMs) in the context of 'Penetrative captive bolt stunning followed by a killing method'*

As for all methods, ABMs related to pain and fear after captive bolt stunning are the signs of consciousness. The same signs of consciousness that are presented for head-only electrical stunning (see list and descriptions in [Table 12](#) and flowchart for use in [Figure 6](#) in Chapter 3.4.3.2) were retrieved from the scientific literature and are therefore suggested for captive bolt.

After the killing process, death should be ensured and any outcome of life will be interpreted as a possibility for sheep and goat to recover consciousness and then be able to experience pain and fear. Therefore, ABMs of state of consciousness and state of death should be used to assess pain and fear in these specific conditions.

3.4.4.3 | *Prevention and correction of welfare consequences and their related hazards during penetrative captive bolt stunning followed by killing method*

Preventive and corrective measures of welfare consequences due to restraint reported under electrical stunning are also appropriate for captive bolt stunning.

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

Selection of people with adequate skills and the right attitude or training them to acquire the skills appropriate to the tasks would help to minimise fear and pain in the animals. Staff training and rotation, use of an appropriate restraint, proper placement and firing of the captive bolt 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 addressed to re-stun as soon as possible in the correct position and direction, and with the correct parameters or administer a back-up killing method without delay. A back-up stunning or killing method or a second captive bolt should be in place and ready to use immediately.

3.4.4.4 | Outcome table on 'Penetrative captive bolt stunning followed by a killing method'

TABLE 14 Outcome table on 'Penetrative captive bolt stunning followed by a killing method'.

Hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Incorrect shooting position	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, presence of other animals in the pen	Staff training and rotation, appropriate restraint of the animal, proper placement of the gun	Stun in the correct position or apply a different killing method
Incorrect captive bolt parameters	Staff, equipment	Lack of skilled operators, wrong choice of equipment, inappropriate cartridge and power, poor cleaning and maintenance of the equipment, too narrow bolt diameter, shallow penetration, low bolt velocity	Staff training, appropriate restraint of the animal, ensuring equipment is fit for the purpose, regular cleaning and maintenance of equipment	Stun with correct parameters and/or apply a different killing method
Overheating of the gun	Staff	Lack of skilled operator, lack of sufficient number of captive bolt guns, lack of resting of captive bolt gun to cool	Staff training, ensuring sufficient number of captive bolt guns are available and rotation of captive bolt guns	None
Prolonged stun-to-kill interval	Staff	Lack of skilled operators, too long time between stunning and killing	Staff training, prompt and accurate application of a killing method	Re-stun and apply a killing method
Incomplete sectioning of the blood vessels	Staff, equipment	Lack of skilled operators, too short or blunt knife	Staff training, use of sharp knife long enough to cut the blood vessels	Re-cut if the animal is unconscious Re-stun before cutting again if the animal is conscious
Ineffective pithing	Staff, equipment	Lack of skilled operator, inappropriate pithing rod	Training of staff, choice of pithing rod appropriate to the size of the animal	Apply pithing correctly
Sublethal dose of chemical or wrong route of administration	Staff	Lack of skilled operator	Training of staff, ensure lethal dose of chemical	Apply lethal dose

ABMs:

Posture, breathing, tonic seizures, palpebral and/or corneal reflex, vocalisations, eye movements (state of consciousness).

Body movements, breathing, corneal or palpebral reflex, heartbeat, pupil size (state of death).

3.4.5 | Non-penetrative captive bolt killing method for lambs and goat kids

Non-penetrative captive bolts have a 'mushroom-headed' bolt tip, which impacts with the skull, but does not enter the brain. This type of equipment causes unconsciousness due to brain concussion and causes death in lambs and goat kids up to 4.5 kg (Grist et al., 2018a, 2018b; goat kids up to 48 h of age by Sutherland et al., 2016). The studies carried out by Grist et al. (2018a, 2018b) involved application of a non-penetrative (percussive) captive bolt to the back of the head and resulted in death in all neonate goats.

The method is usually applied on restrained animals.

Grist et al. (2018a) concluded, based upon indicators of brain death, that the Accles & Shelvoke CASH Small Animal Tool (CPK 200) is an effective single shot killing device for neonate lambs, provided the shot position on the midline at the back of the head with the chin tucked in (Figure 12) and a 1.25-grain cartridge is used.

Grist et al. (2018b) concluded that the use of the CASH Small Animal Tool (CPK 200) can be recommended for killing of neonatal goat kids when fired on the midline between the ears, with the chin tucked into the neck (Figure 12) is used in conjunction with a 1 grain cartridge.

According to the AVMA guidelines (AVMA, 2020; Figure 13), the preferred shooting position in neonatal lambs and kids is with the muzzle of the NPCB on the midline behind the poll (i.e. between the ears) with the chin tucked into the neck (Sutherland et al., 2016).

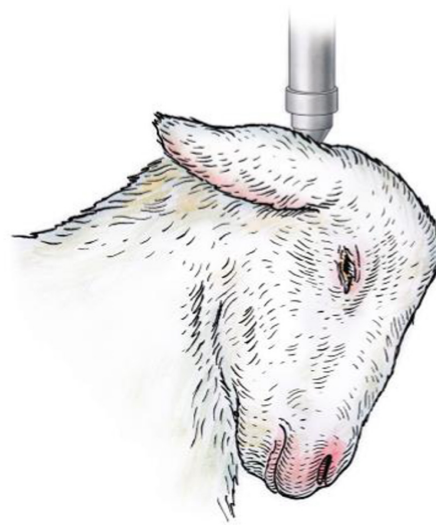


FIGURE 13 Non-penetrative captive bolt stunning shooting position for neonatal lambs and goat kids (AVMA, 2020).

When applying to young lambs (under 9 kg), a non-penetrative captive-bolt device with sufficient power (≥ 50 Joules) applied to the head, it has to be followed by the severing of the neck vessels (carotid arteries and jugular veins) as a small proportion of the lambs are only stunned and not killed (HSA, 2017).

The EU regulation 1099/2009 permits the use of non-penetrative captive bolt as a reversible stunning method in animals of less than 10 kg. It is not a killing method for animals of less than 10 kg.

For sheep and goats of more than 10 kg, there is not enough information to conclude if non-penetrative captive bolt is an effective stunning method and the use of non-penetrative captive bolt is not allowed by EC regulation 1099/2009.

3.4.5.1 | Hazard identification for 'non-penetrative captive bolt killing method' for lambs and goat kids

The hazards (excluding ineffective pithing) are the same as for penetrative captive bolt stunning (see Section 3.4.4.1). These hazards will lead to persistence of consciousness or resumption of consciousness.

3.4.5.2 | ABMs for assessment of non-penetrative captive bolt

ABMs related to consciousness are the same ABMs as the ones suggested for electrical stunning (see Section 3.4.3.2).

3.4.5.3 | Prevention and correction of welfare consequences and their related hazards during non-penetrative captive bolt stunning

See Section 3.4.4.2.

About back-up method in the case of failure of the first shot, another killing method should be applied.

3.4.5.4 | Outcome table for non-penetrative captive bolt stunning followed by killing

TABLE 15 Outcome table on 'non-penetrative captive bolt stunning (followed by a killing method)'.

Hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Incorrect shooting position	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 animal, proper placement of the gun	Shoot in the correct position or apply a different killing method
Incorrect captive bolt parameters	Staff, equipment	Lack of skilled operators, wrong choice of equipment, inappropriate cartridge and power, poor cleaning and maintenance of the equipment, too narrow bolt diameter, shallow penetration, low bolt velocity	Staff training, appropriate restraint of the animal, ensuring equipment is fit for the purpose, regular cleaning and maintenance of equipment	Stun with correct parameters and/or apply a different killing method
Overheating of the gun	Staff	Lack of skilled operator, lack of sufficient number of captive bolt guns, lack of resting of captive bolt gun to cool	Staff training, ensuring sufficient number of captive bolt guns are available and rotation of captive bolt guns	Rest overheated captive bolt gun for the barrel to cool off
Prolonged stun-to-kill interval	Staff	Lack of skilled operators, too long time between stunning and killing	Staff training, prompt and accurate application of a killing method	Re-stun and apply a killing method

ABMs:

Posture, breathing, tonic seizures, palpebral and/or corneal reflex, vocalisations, eye movements (state of consciousness).

Body movements, breathing, corneal or palpebral reflex, heartbeat, pupil size (state of death).

3.4.6 | Percussive blow to the head followed by killing (also called blunt force trauma)

According to Reg. 1099/2009, percussive blow to the head is a one-step method for killing neonatal sheep and goats (up to 5 kg live weight).

According to the HSA (2017), there are two variations of this method:

- Hold the animal by the hind legs and deliver a firm blow to the back of the head with a blunt instrument, e.g. an iron bar or hammer (Figure 13). This method requires restraint of the animal and presentation of the animal in upside down position.
- Hold the animal by the hind legs and swing it through an arc to hit the back of its head with considerable force against a solid object, e.g. a brick wall or metal stanchion.

In both procedures, it is essential that the blow is delivered swiftly, firmly, with enough force and with absolute determination to provoke severe damage to the brain and the immediate unconsciousness (HSA, 2017). If there is any doubt that the animal has not been killed effectively, the blow should be immediately repeated. However, if a skull fracture occurred due to the first blow, it is very unlikely that the second blow will lead to brain concussion (EFSA, 2004).

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

There is no published scientific data evaluating the effectiveness of percussive blow to the head/blunt force trauma. However, to be effective it must involve a single blow to the correct position on the cranium of enough force to produce immediate depression and severe damage to 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 a 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. Alternately, intravenous injection of euthanising chemicals such as saturated solution of KCl or MgSO₄ may be given to unconscious animals.

In a previous EFSA opinion (pigs ref), this method is mainly performed by holding a piglet 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 piglet with both hands around its hindlegs and swinging the piglet's head towards a hard surface.

The same procedures could be applied to small ruminant neonates of below 5 kg. Delivering a blow to the forehead with a hard object or hitting the head towards a hard surface is entirely manual process and prone to error. It requires a level of skill that most stockpersons and veterinarians would unlikely possess if they infrequently performing the procedure. Consequently, the probability of achieving an immediate killing is low (Grist et al., 2017), and therefore, the EFSA experts, based on their expert opinion, recommend that it is not used as an on-farm killing method. Furthermore, this method requires inversion of the animals and therefore induces severe welfare consequences related to handling (see also chapter 3.5 for the acceptability/non-acceptability of the method).

3.4.6.1 | Hazard identification for 'percussive blow to the head'

Hazards are:

1. Inversion (during restraint)
2. Incorrect application of blow to the head

Inversion:

Manual blunt force trauma might be performed by holding the animal in an upside-down position and swinging the animal's head towards a hard surface or delivering a blow to the head using a hard object. This position and movement will cause fear.

Incorrect application of the blow to the head:

If animals are not hit on the frontal–parietal bones (wrong location) or the force is not sufficient to induce concussion, the method will fail to induce immediate unconsciousness and will cause pain. Lack of skilled operators (wrong location and insufficient force), operator fatigue and poor restraint and wrong choice of the tool to deliver the blow can lead to incorrect application of blow to the head.

3.4.6.2 | *ABMs for assessment of percussive blow to the head*

ABMs related to consciousness are the same ABMs as the ones suggested for electrical stunning (see Section 3.4.3.2).

3.4.6.3 | *Prevention and correction of welfare consequences and their related hazards during delivery of percussive blow to the head*

There are no preventive or corrective measures to the pain and fear caused by manual restraint and inversion as this is part of the killing method. Therefore, it is preferable to choose a different method like non-penetrative captive bolt. Non-penetrative captive-bolt devices have the advantage of relying less 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 (such as a hard metal pipe or a club) and delivery of accurate blow.

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

Inadequate stunning should be corrected without delay by application of an adequate back up procedure, i.e. lethal injection.

3.4.6.4 | Outcome table on 'Percussive blow to the head' stunning followed by a killing method

TABLE 16 Outcome table on 'Percussive blow to the head' stunning followed by a killing method'.

Hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Inversion	Staff	Manually inverting animals for the application of the blow to the head	None	None
Incorrect application of the blow to the head	Staff	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 accurate and adequate force, use appropriate tool	Correct application of the method

ABMs:

Posture, breathing, tonic seizures, palpebral and/or corneal reflex, vocalisations, eye movements (state of consciousness).

Body movements, breathing, corneal or palpebral reflex, heartbeat, pupil size (state of death).

3.4.7 | Firearms with free projectile

Shooting animals outdoors from a distance does not require any restraint. Shooting indoors might request to at least restrict the movement of the animal in a smaller pen. According to the AVMA (2020) firearms recommended for killing of adult sheep and goats include the 0.22" long rifle; 0.38" Special, 0.357" Magnum, and 9 mm or equivalent handguns; and shotguns. Some operators prefer hollow-point bullets to increase brain destruction and reduce the risk of ricochet. However, operators are reminded that bullet fragmentation may substantially reduce the potential for brain destruction because of reduced penetration, particularly when used in large-horned adult rams. Shotguns or higher calibre firearms loaded with solid-point bullets are preferred in these conditions. When firearms are used for killing, it is important that the gun never be held flush with the skull. Instead, the muzzle of the gun should be aimed in the desired direction and held no closer than 6–12 inches from the target. The best site for firing is on the intersection of two lines, each of which is drawn from the lateral canthus of one eye to the middle of the base of the opposite ear (Figure 10; AVMA, 2020). Alternative landmarks that provide a very similar placement use the dorsal midline of the head at the level of the external occipital protuberance aiming downward towards the cranial most portion of the intermandibular space (Figure 11; AVMA, 2020). Frontal shots, aiming at the foramen magnum, should be reserved for use only with gunshot and provide an alternate approach for heavily horned sheep and goats where the top of the skull may be too hard to access due to the horns.

3.4.7.1 | Hazard identification for 'Firearms with free projectile'

The hazards are:

1. Incorrect shooting position;
2. Inappropriate power and calibre of the cartridge;
3. Inappropriate type of projectile.

Incorrect shooting position:

According to the Humane Slaughter Association (HSA, 2017) when shooting sheep and goats with a free-bullet firearm, the aiming point is on the midline, just above the eyes, directed down the line of the spine into the bulk of the body. In practice, this can be quite difficult to achieve and a slight error in the angle of shot, or minor movement on the part of the animal, can result in a free-bullet exiting from the animal's head or neck.

Heavily horned sheep and goats can present a problem where a free-bullet weapon is used. The mass of horn over the forehead can leave little or no target area: A shot between the eyes is too low and should not be used under any circumstances. Such animals can be shot from behind the poll (AVMA, 2020). However, this is dangerous with a free-bullet weapon and, if undertaken, the animal should always be situated on soft ground or sand pit to avoid ricochet. Where possible, a shotgun is recommended for this type of shot.

Incorrect shooting position can occur due to bad weather conditions (wind) in the field, and sudden movement of the target animal or its head. In addition, 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.

Inappropriate power and calibre of the cartridge

Ineffective shooting might occur when the chosen firearm and projectile are inappropriate for the animal to cause immediate death. It can occur when using underpowered ammunition designed for use in target shooting, which therefore fails to penetrate; or when using metal-jacketed (metal sleeved) ammunition which over-penetrates without distorting enough to cause sufficient damage to the brain (HSA, 2017).

Inappropriate type of projectile:

Metal sleeved or jacketed high velocity bullets may exit the skull without causing destruction of the brain and therefore bullets that are designed and constructed to deform or fragment within the skull should be used.

3.4.7.2 | ABMs for assessment of firearms with free projectile

ABMs related to consciousness are the same ABMs as the ones suggested for electrical stunning (see Section 3.4.3.2).

3.4.7.3 | Prevention and correction of welfare consequences and their related hazards during the use of firearms with free projectile

The use of appropriate firearm and ammunition are 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 for appropriate selection of ammunition, accurate shooting and use of adequate procedures to monitor (un)consciousness will benefit to prevent and correct shooting failures. Inadequate shooting should be corrected, without delay, by application of a second shot or an adequate back-up killing method.

3.4.7.4 | Outcome table on 'Firearm with free projectile' killing

TABLE 17 Outcome table on 'Firearm with free projectile killing method'.

Hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Incorrect shooting position	Staff	Lack of skilled operator, operator fatigue, shooting in wrong place	Staff training and rotation	Re-shoot the animal in the correct position
Inappropriate power and calibre of the projectile	Staff, equipment	Lack of skilled operator, wrong choice of equipment and projectile, poor maintenance of the equipment	Staff training, appropriate equipment and projectile	Correct application of the power and calibre Apply another killing method

ABMs:

Posture, breathing, tonic seizures, palpebral and/or corneal reflex, vocalisations, eye movements (state of consciousness).

Body movements, breathing, corneal or palpebral reflex, heartbeat, pupil size (state of death).

3.4.8 | Lethal injection

Overdose of an anaesthetic drug can be used as a sole method to kill sheep and goats of all ages and weight groups.

Lethal injection requires restraint. Administered by intravenous injection, barbiturates induce a smooth transition from consciousness to unconsciousness and death by causing depression of the central nervous system and respiratory centres in the brain leading to cardiac arrest (AVMA, 2020). This method is used to kill sick and injured animals or as a secondary killing procedure in the field. The preferred route of administration is intravenous (AVMA, 2020). Intracardiac administration can be extremely painful if penetration of the heart is not successful on the first attempt (EFSA, 2004). The intracardiac route thus should not be used in conscious animals.

Other chemical agents such as T-61, a combination of embutramide, mebezonium iodide and tetracaine hydrochloride, and saturated solutions of potassium chloride or magnesium sulfate are also used for killing. However, the welfare impact of this practice has been questioned. Concerns with T-61 include the potential for causing pain and irritation during rapid injection, and paralysis, which can result in the suppression of respiration prior to the onset of unconsciousness. Similarly, potassium chloride and magnesium sulfate lead to painful cardiac arrest (EFSA, 2004). Because of these serious concerns, T-61, potassium chloride and magnesium sulfate should not be used as killing method in conscious animals.

3.4.8.1 | Hazard identification for 'lethal injection'

The hazards are:

1. Inappropriate route of administration
2. Sublethal dose

Inappropriate route of administration

Any route of administration different from the ones recommended by the manufacturer happening for any reason, including untrained operators, or animals allowed to move during the administration of the drug will lead to a wrong route of administration (e.g. non-intravenous).

Sublethal dose

Use of a dose that is less than the one recommended by the manufacturer to kill a small ruminant according to its weight.

Individual animal may have to be weighed in order to calculate lethal dose; otherwise, some animals will receive less than lethal dose required to causing rapid death.

3.4.8.2 | ABMs for assessment of lethal injection

ABMs related to pain and fear after application of the lethal injections are the ABMs of the state of consciousness. These ABMs of the state of consciousness are posture, breathing, corneal or palpebral reflex, vocalisation and eyes movements. At the end of the killing procedure, animals should be checked for signs of death to prevent that animals that are not dead are being disposed. These ABMs are the same as those suggested for electrical stunning (see Section 3.4.3.2).

3.4.8.3 | Prevention and correction of welfare consequences and their related hazards during the use of lethal injection

Preventive methods to avoid the above-described hazards and their welfare consequences are follow the manufacturer's instructions, use the intravenous (IV) route for injection, train staff to use appropriate restraint and presentation of the animal to avoid extravasation of the drug and use the correct dose according to the live weight of animals.

To prevent the risk of discarding sheep and goats alive, it is essential to examine individual animals for signs of life and kill them without delay (corrective measures) by giving a lethal injection of an anaesthetic drug if they are conscious or of a lethal substance to kill them in case they are still alive but unconscious (see AVMA, 2020 for details).

3.4.8.4 | Outcome table on 'lethal injection'

TABLE 18 Outcome table on 'Lethal injection'.

Hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Inappropriate route of administration	Staff	Lack of skilled operators, inappropriate restraint, selection of wrong route of administration	Staff training, follow the manufacturer's instructions, use appropriate restraint	Adjust the route of administration
Sub-lethal dose	Staff	Administration of wrong dose of drug	Staff training, read the manufacturer's instructions to calculate dose appropriate to live weight	Re-inject with right amount of drug

ABMs:

Posture, breathing, tonic-clonic seizures, palpebral and/or corneal reflex, vocalisations, eye movements (state of consciousness).

Body movements, breathing, corneal or palpebral reflex, heartbeat, pupil size (state of death).

3.4.9 | Gas killing methods

Controlled atmosphere stunning methods are not allowed in Council Regulation (EC) No 1099/2009 for sheep and goats and are not listed in Chapters 7.5 and 7.6 of the WOAH guidelines. The exposure to high concentrations of CO₂ has been evaluated in a limited number of research papers (Bornez et al., 2009a, 2009b, 2010; Rodriguez et al., 2016). Sheep are effectively stunned by exposure to CO₂ at high concentrations. Lambs exposed to 90% CO₂ will lose consciousness in on average 48 s, but to ensure death, they should be exposed to the gas concentration for longer periods (Rodriguez et al., 2016).

However, before the loss of consciousness, lambs exhibited headshake and sneezing, gasping and increased respiration rate (Rodriguez et al., 2016). The fact that these behaviours occur when the animal is conscious, is evidence that the exposure to CO₂ at high concentrations does not cause immediate loss of consciousness and lambs may experience discomfort, pain, fear and/or distress. This aversion might be similar to that experienced by other species, such as pigs, where high concentration of CO₂ is used for commercial slaughter.

3.4.10 | Disposal of animals while being still alive as a common hazard to all killing methods

Although all the methods described here are intended to kill the animals, there is always a risk that the animals are not dead due to ineffective application of the killing method. The fact that animals are still alive is considered a hazard to animal welfare since it cannot be excluded that they will recover consciousness. In this case animals would be able to experience pain and fear as a consequence of the killing method being ineffective (e.g. injury to the skull resulting from mechanical method, irritation due to chemical product injected in peri-venous tissue, etc.).

Lack of monitoring and confirmation of death can lead to the disposal of live animals, potentially exposing them to pain and fear.

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 the WOAH and EC Regulation 1099/2009 on unacceptable methods and practices. EC Regulation 1099/2009 presents a list of methods of restraint that are prohibited. Some of these methods are related to the killing of sheep and goats on farm:

- suspending or hoisting conscious animals (including neonates for performing percussive blow to the head);
- mechanical clamping or tying of the legs or feet of animals;
- severing the spinal cord, such as using a puntilla or dagger;
- the use of electric currents to immobilise the animal that do not stun or kill it under controlled circumstances, and, in particular, any electric current application that does not span the brain.

Similarly, the Panel agrees with the principle in Chapter 7.5.10 of the WOAH Terrestrial code (OIE, 2019), which says that 'methods and practices e.g. restraining methods [...] that cause severe pain and stress in animals, cannot be considered acceptable'.

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

- Moving severely injured animals or those unable to move independently.
- Use of painful procedures to move animals (e.g. use of electric goads, electrical stunning tong)
- Use of painful handling to move animal (e.g. lifting or pulling of sheep and goats by wool, skin fold, horn or by legs/tail).
- Painful induction of death in conscious animals (e.g. T-61 or potassium chloride or magnesium sulfate, intracardiac administration of a drug, application of an electric current across the chest to induce cardiac arrest or sticking of conscious animals).
- Methods that do not induce unconsciousness but only tranquillise animals without killing them (deep tranquilisation as with xylazine or other alpha-2 agonist) followed by injection of saturated solutions of potassium chloride or magnesium sulfate.
- Sticking and bleeding of conscious animals.

Furthermore, there are no documented scientific data on the effectiveness of a percussive blow to the head using a hard object such as a hammer, club or a metal pipe to induce unconsciousness. However, according to expert opinion, this method is prone to a high failure rate thus leading to severe pain. These should be replaced by other practices, which result in less severe pain. In addition, most of the hazards originate from staff, and therefore, the Panel considers the lack of understanding or skills or lack of training of the staff working in the killing of animals a serious concern. Finally, the Panel is convinced that methods, which are likely to be highly painful, but have not been scientifically evaluated, such as inflicting injuries and wounds leading to death, burying, drowning, suffocating, addition of toxic substances to feed or water, injection of air as well as injection of chemical agents or other substances not specifically designed or labelled for killing (i.e. disinfectants, cleaning solutions, etc.) must not be used to kill animals.

3.6 | Specific hazards related to types of animals or species (ToR 4)

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

Pregnant animals

The EFSA experts considered this issue and concluded, based on a previous EFSA opinions (EFSA AHAW Panel, 2017), that it is from extremely unlikely to unlikely (i.e. with 1%–33% likelihood) that there are welfare consequences specifically occurring to the fetuses. Therefore, there is no specific measure to be taken for killing of pregnant dams.

Extensively raised animals

Extensively raised animals generally are more fearful of humans than animals that are used to humans and will more likely experience handling stress, so extra care should be taken to handle and restrain them.

3.7 | Results of the uncertainty assessment

Table 19 shows the conclusions and the questions including well-defined quantities of interest (QoI) used in the uncertainty analysis for the key conclusions (see Section 2.2.5 for explanation on the methodology for uncertainty assessment). These QoI were formulated assuming that a given welfare consequence would apply to a significant proportion of animals in a population, with proportions varying depending on the context of the question. For each question, experts were asked to provide their individual judgements along with the rationale supporting it, and then a consensus certainty range reflecting their collective uncertainty about the statement was reached through group discussion or, if no consensus was achieved, the wider range encompassing all individual judgements was used.

For all questions, it was assumed that the practice/method is applied correctly e.g. correct position or application for a sufficient time period.

TABLE 19 Conclusions and questions for uncertainty assessment, and final consensus certainty range.

Conclusion	Method	Question for uncertainty assessment	Certainty range
1 For a single step electrical killing method, a current of 1 A or more applied for a minimum 2 seconds delivered using 50 Hz sinewave alternating current spanning the brain and the hearth simultaneously is effective in stunning and killing of sheep and goats	Single step electrical killing method	How certain are you that 99% or more sheep will be effectively stunned and killed when using a current of 1 A or more applied for a minimum 2 seconds delivered using 50 Hz sinewave alternating current?	90%–100%
		How certain are you that 99% or more goats will be effectively stunned and killed when using a current of 1 A or more applied for a minimum 2 seconds delivered using 50 Hz sinewave alternating current?	90%–100%
2 For a two-step electrical killing method, a current of 1 A or more delivered using 50 Hz sinewave alternating current across the head spanning the brain and across the chest spanning the heart is effective in stunning and killing sheep and goats.	Two-step electrical killing method	How certain are you that 99% or more sheep will be effectively stunned and killed when using a current of 1 A or more delivered using 50 Hz sinewave alternating current applied for a minimum 2 seconds across the head spanning the brain and applied for a minimum 3 seconds across the chest spanning the heart?	90%–100%
		How certain are you that 99% or more goats will be effectively stunned and killed when using a current of 1 A or more delivered using 50 Hz sinewave alternating current across the head spanning the brain and across the chest spanning the heart?	90%–100%

TABLE 19 (Continued)

Conclusion	Method	Question for uncertainty assessment	Certainty range
8 Non-penetrative captive bolt applied in the midline on the back of the head position on the occipital bones is a killing method for lambs and goat kids weighing up to 4.5 kg	Non-penetrative captive bolt killing	How certain are you that 99% or more lambs weighting up to 4.5 kg are killed using non-penetrative captive bolt applied in the midline on the back of the head position on the occipital bones?	90%–100%
		How certain are you that 99% or more goat kids weighting up to 4.5 kg are killed using non-penetrative captive bolt applied in the midline on the back of the head position on the occipital bones?	90%–100%
9 For lambs and goat kids in between 4.5 and 10 kg, non-penetrative captive bolt is a reversible stunning method	Non-penetrative captive bolt stunning	How certain are you that more than 99% of lambs between 4.5 kg and 10 kg will be stunned when using non-penetrative captive bolt?	90%–100%
		How certain are you that more than 99% of goats between 4.5 kg and 10 kg will be stunned when using non-penetrative captive bolt?	90%–100%
		How certain are you that less than 99% of lambs between 4.5 kg and 10 kg will be killed when using non-penetrative captive bolt?	90%–100%
		How certain are you that less than 99% of goats between 4.5 kg and 10 kg will be killed when using non-penetrative captive bolt?	90%–100%
10 Percussive blow to the head on lambs and kid goats weighing less than 5 kg is an entirely manual process and therefore the impact energy delivered to the brain will vary and may not always be sufficient to induce immediate unconsciousness		How certain are you that less than 99% of sheep and goats weighing less than 5 kg will be immediately stunned or killed when using percussive blow to the head?	90%–100%
11 Sheep and goats can be effectively stunned and killed by exposure to CO ₂ at high concentrations (higher than 90% by volume)	Gas stunning	How certain are you that 99% or more sheep and goats will be stunned and killed by exposure to CO ₂ at high concentrations (higher than 90% by volume)?	66%–100%
12 Exposure to CO ₂ at high concentrations (higher than 90% by volume) causes pain and fear in sheep and goats such in other species like pigs		How certain are you that 50% or more sheep and goats exposed to high CO ₂ will experience pain and fear?	90%–100%

4 | CONCLUSIONS

Preamble: The on-farm killing process is divided into two phases: Phase 1, which involves handling and moving the animals to the killing site and restraining them before the killing methods are applied, and Phase 2, which involves stunning/killing the animals.

4.1 | General conclusions

1. During the on-farm killing processes, sheep and goats can experience negative welfare consequences during handling and moving and during restraint for killing. Furthermore, during application of the killing method, sheep and goats which are still conscious will experience pain and fear due to the killing process itself.
2. Some hazards can be present only during moving and handling, but the welfare consequence of these hazards may persist during the killing process until the animal is rendered unconscious (e.g. injuries resulting from inappropriate handling).
3. During the on-farm killing process, most of the hazards identified are associated with lack of specific skills and training of the staff, and with poorly designed or constructed facilities. The lack of skills and/or training of the staff involved in on-farm killing is considered a serious welfare concern by the Panel.

4.2 | Conclusions specific for 'handling and moving'

4. The welfare consequences during handling and moving are restriction of movements, handling stress and injuries. The associated ABMs are slipping, falling and trampling (restriction of movements), escape attempts, reluctance to move, vocalisations (handling stress), skin lesions and wounds, bone fractures and dislocated joints (for injuries).
5. Moving severely injured sheep and goats will exacerbate their pain, which is considered a serious welfare concern by the Panel.
6. Rushing the animals may cause handling stress and injuries, as well as animals to be more difficult to handle subsequently (e.g. during restraint for killing).
7. The use of painful stimuli for handling and moving of the animals is considered a serious welfare concern by the Panel.
8. The use of trained leader sheep and trained dogs can facilitate the movement of sheep.
9. Extensively raised animals are a specific animal category as they generally are more fearful of humans and will experience more handling stress than animals that are used to humans.

4.3 | Conclusions specific to the on-farm killing process

1. The killing process includes restraint (for some methods) and application of the killing method. The methods requiring restraint are electrical methods, mechanical (excluding firearms) methods and lethal injection.
2. During restraint, the welfare consequences are restriction of movement, handling stress and soft tissue lesions. Associated ABMs are vocalisation, escape attempts, facial expressions, grinding of teeth and curling of lips (handling stress, restriction of movements, injuries) and skin lesions and wounds (injuries). These welfare consequences will persist during the restraining period until loss of consciousness.
3. During application of the killing method, sheep and goats will experience pain and fear if they are ineffectively stunned or if they recover consciousness. ABMs related to the state of consciousness can be used to indirectly assess pain and fear.
4. In two-step killing methods (i.e. methods that induce simple stunning and require a second step to cause death), the delayed application of the second step (killing method) increases the risk of recovery of consciousness before death occurs.
5. For electrical methods, the main hazards leading to ineffective stunning are the inappropriate restraint, wrong placement of the electrodes, poor electrical contact, too short exposure time and inappropriate electrical parameters.
6. The AHAW Panel concluded with 90%–100% certainty that for a single-step electrical killing method, a current of 1 A or more applied for a minimum 2 seconds delivered using 50 Hz sinewave alternating current spanning the brain and the heart simultaneously is effective in stunning and killing of sheep and goats.
7. The AHAW Panel concluded with 90%–100% certainty that, for a two-step electrical killing method, a current of 1 A or more applied for a minimum 2 seconds delivered using 50 Hz sinewave alternating current across the head spanning the brain and across the chest spanning the heart is effective in stunning and killing sheep and goats.
8. For electrical methods, the higher the thickness of fleece, the higher the electrical resistance that will reduce the current flow and the stunning and killing efficacy.
9. For electrical methods, the pressure applied to the electrodes will impact the contact between the head and the electrodes and hence the current flow and the stunning efficacy.
10. For head-only electrical stunning, the placement of the electrodes on the temporal bones offers the least electrical resistance to the current flow.
11. For head-only electrical stunning, the presence of horns impedes the correct placement of the electrodes on the temporal bones.
12. Penetrative captive bolt stunning is considered a reversible stunning method since it does not lead to death in all animals, and therefore, a secondary procedure applied without delay (e.g., pithing) is required to induce death in unconscious animals and avoid animals to experience further welfare consequences.
13. For captive bolt stunning, the hazards are incorrect position and direction of the shot, incorrect captive bolt parameters and the overheating of the captive bolt gun.
14. For polled sheep, the most effective shooting position when using a penetrative captive bolt is on the highest point of the head, and on the midline, aiming straight down.
15. For horned sheep and goats, the most effective shooting position when using a penetrative captive bolt is behind the ridge between the horns (behind the bony mass) and aimed towards the base of the tongue.
16. The presence of thick frontal bones and sinuses in horned sheep reduces the effectiveness of both penetrating and non-penetrating captive bolt shooting on the frontal bone.
17. The AHAW Panel concluded with 90%–100% certainty that non-penetrative captive bolt applied on the midline, between the ears, with the chin tucked into the neck can be used as a killing method for lambs and goat kids weighing up to 4.5 kg.
18. The AHAW Panel concluded with 90%–100% certainty that non-penetrative captive bolt is a reversible stunning method for lambs and goat kids between 4.5 and 10 kg.

19. Percussive blow to the head is allowed on lambs and kid goats weighing less than 5 kg and is an entirely manual process. The AHAW Panel concluded with 90%–100% certainty that the impact energy delivered to the brain varies and is not always sufficient to induce immediate unconsciousness.
20. For percussive blow to the head, the main hazards leading to pain and fear are inversion and incorrect application of the blow to the head.
21. For firearms, the main hazards are the inappropriate power and calibre of the cartridge, inappropriate type of projectile and incorrect shooting position (e.g. heavily horned sheep and goats requiring shooting from the back to avoid the risk of ricochet).
22. For lethal injections, the main hazards are the inappropriate route of administration and sublethal dose.
23. The Panel has serious concerns about the following practices as they will induce severe pain:
 - The application of percussive blow to the head using a hard object such as metal pipes, sticks or a hammer;
 - Application of electric current from the head to the floor to induce cardiac arrest in conscious animals;
 - Painful induction of death (e.g. T-61, intracardiac administration of a drug, application of an electric current across the chest to induce cardiac arrest or sticking of conscious animals);
 - Electro-immobilisation of conscious animals;
 - Methods that do not induce unconsciousness but only tranquillise animals without killing them (deep tranquillisation as with xylazine or other alpha-2 agonist) followed by injection of saturated solutions of potassium chloride or magnesium sulfate;
 - Sticking or bleeding of conscious animals,
 - Inflicting injuries and wounds leading to death,
 - Burying, drowning or suffocating,
 - Addition of toxic substances to feed or water,
 - Injection of air as well as injection of chemical agents or other substances not specifically designed or labelled for killing (i.e. disinfectants, cleaning solutions, etc.)
24. When killing is unsuccessful, sheep and goats are subjected to the risk of being disposed alive and therefore recover consciousness with the possibility to experience pain and fear.
25. Killing sheep and goats with gas mixtures has the advantage of not requiring restraint, but it has the disadvantage that it does not lead to immediate onset of unconsciousness.
26. The AHAW Panel concluded with 90%–100% certainty that sheep and goats can be effectively stunned by exposure to CO₂ at high concentrations (higher than 90% by volume).
27. The AHAW Panel concluded with 66%–100% certainty that sheep and goats can be effectively killed by exposure to CO₂ at high concentrations (higher than 90% by volume).
28. The AHAW Panel concluded with 90%–100% certainty that exposure to CO₂ at high concentrations (higher than 90% by volume) is an aversive method as it causes pain and fear in sheep and goats such as in other species like pigs.
29. No information is available on the use of inert gases and CO₂ with inert gases for killing of sheep and goats.

5 | RECOMMENDATIONS

5.1 | General recommendations

1. Design, construction and maintenance of the farm and handling facilities should be based on understanding how sheep and goats perceive their environment and meet their welfare requirements to prevent as much as possible restriction of movements, handling stress and injuries before killing on farm.
2. All processes of the killing should be carried out by trained and skilled personnel. Staff should be trained to have a good understanding of species-specific behaviour and to act accordingly during all phases.
3. The welfare of sheep and goats should be assessed at each phase of the killing process to prevent and correct hazards and mitigate their welfare consequences.
4. When a hazard is identified during killing of an animal, it should be corrected without any delay and prevented in order to avoid it in the other animals.
5. Farms should have standard operating procedures (SOPs) which should include identification of hazards and related welfare consequences, using relevant ABMs, as well as preventive and corrective measures. The SOP should be reviewed and updated periodically based on the experiences from previous operations.

5.2 | Recommendations specific to phase 1- handling and moving

6. Ideally, sheep and goats should be killed in their home pens or pastures and carcasses moved for disposal. This especially applies to sheep and goats, that are lame, injured, show signs of severe pain, signs of illness or those unable to move without assistance, and it equally applies to neonates.

7. If movement of sheep and goats is required, the distance to the point of killing should be kept to a minimum and the animals should be moved gently.
8. Animals should not be forced to move faster than their normal, unhindered walking pace.
9. Painful stimuli, such as electric goads, hitting with a stick, lifting or pulling by wool and skin fold or horns, should not be used. Instead, softer stimuli such as flags, plastic paddles or streamers should be used.
10. When lead sheep or dogs are used to handle and move the animals, they should be trained.
11. Extensively raised animals should be handled with extra care since they are typically more fearful of humans.

5.3 | Recommendations specific to phase 2- killing

1. To spare them from welfare consequences, animals should be restrained appropriately: Equipment for restraint should be adjusted to the size of the animal category; head collar and lead rope, halter or bridle may be used to secure and to restrict movement of the head of animals; duration of restraint should be as short as possible, and animals must be restrained only when operator and the equipment are ready to proceed to the stunning and killing procedures; use of strawbales or wooden boards to construct temporary 'stun boxes' should be considered (in case of stunning of animals in groups).
2. Application of reversible stunning methods should be followed by a killing method without delay.
3. Pithing of sheep and goats stunned with a penetrative captive bolt must be performed without any delay after stunning. The pithing rod should be appropriate to the size of sheep and goats and capable of destroying brain stem and upper spinal cord.
4. For polled sheep, the muzzle of the penetrative captive bolt stunner should be placed on the highest point of the head, and on the midline, aiming straight down.
5. For sheep and goats with horns, the muzzle of the penetrative captive bolt stunner should be placed in the pole position on the midline, behind the ridge between the horns (behind the bony mass) and aimed towards the base of the tongue.
6. The use of non-penetrative captive bolt as killing method should be restricted to lambs and kid goats weighing up to 4.5 kg. For animals weighing 4.5–10 kg, a killing method should be applied after the application of the non-penetrative captive bolt. To monitor the efficacy of the killing method, the state of consciousness should be checked immediately after stunning, and death should be confirmed after the application of a killing procedure and before carcass disposal – using the suggested ABMs.
7. For electrical stunning of sheep and goats (one cycle and two cycles), it is recommended to use a current of 1.0 A or more delivered at 50 Hz sine wave alternating current for at least 2 s.
8. When a two-cycle electrical method is used to kill sheep and goats on farm, the second current cycle should be applied across the chest without any delay and always during the tonic seizures that occur after the application of the first current cycle across the head.
9. In order to improve the efficacy of head-only electrical stunning of sheep, the pins of the tongs should be long enough to penetrate the fleece in order to make contact with the skin and be wetted to increase the electrical contact.
10. Percussive blow to the head of neonatal sheep and goats should not be used.
11. Lethal injection of anaesthetic drugs should be performed strictly following the manufacturer's instructions in relation to dose, route and rate of administration.
12. A back-up killing method should be readily available at any time and be applied immediately in case of failure of the initial method.
13. Killing sheep and goats with methods that are severely painful should not be used on welfare grounds. These include, for example, inflicting injuries and wounds leading to death, burying, drowning, suffocating, addition of toxic substances to feed or water, injection of chemical agents or other substances not specifically designed or labelled for killing (i.e., disinfectants, cleaning solutions, etc.), air injection into blood vessels and deep tranquilisation as with xylazine or other alpha-2 agonist followed by potassium chloride or magnesium sulfate.
14. More research is recommended on the use of inert gases and CO₂ with inert gases for killing of sheep and goats.

ABBREVIATIONS

A	Ampere
ABM	animal-based measure
EEG	electroencephalogram
EKE	Expert Knowledge Elicitation
EFSA	European Food Safety Authority
Hz	Hertz
NPCB	non penetrative captive bolt
PCB	penetrative captive bolt
V	volt
WC	welfare consequence
WOAH	World Organisation for Animal Health

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CONFLICT OF INTEREST

If you wish to access the declaration of interests of any expert contributing to an EFSA scientific assessment, please contact interestmanagement@efsa.europa.eu.

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PANEL MEMBERS

Julio Alvarez, Dominique Joseph Bicout, Paolo Calistri, Elisabetta Canali, Julian Ashley Drewe, Bruno Garin-Bastuji, Jose Luis Gonzales Rojas, Christian Gortazar Schmidt, Mette Herskin, Virginie Michel, Miguel Angel Miranda Chueca, Søren Saxmose Nielsen, Barbara Padalino, Helen Clare Roberts, Hans Spoolder, Karl Stahl, Antonio Velarde, Arvo Viltrop and Christoph Winckler.

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APPENDIX A

Literature search outcomes for sheep and goats

As described in Section 2.2.2, a literature search was carried out to identify peer-reviewed scientific evidence on the topic of 'slaughter and killing of sheep and goats' 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 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 'sheep and goats'. 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: 27 January 2024 (Restriction to English).

Web of science search string	
Years 2004–2024	
Search terms	Category
TS=small ruminants OR TS=small ruminant OR TS=sheep OR TS=goats OR TS=goat OR TS=lambs OR TS=lamb OR TS=kids OR TS=kid OR TS=muttons OR TS=mutton OR TS=rams OR TS=ram OR TS=billy-goats OR TS=billy-goat OR TS="Ovis aries" OR TS="Capra aegagrus hircus"	Topic
AND	
TS=handl* OR TS=mov* OR TS=restrain* OR TS=stun* OR TS=kill* OR TS=cut* OR TS=bleed* OR TS=conscious* OR TS=pain* OR TS=death	Title
AND	
TS=Welf* OR TS="animal welfare"	Topic
Results: 118	
Results after screening for relevance: 55	
Results after final screening: 19	

Refinement of literature search results

The search yielded a total of 118 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 then 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 55 relevant records. Discrepancies were discussed between the EFSA experts until a final subset of 18 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 and killing of sheep and goats' resulting from the literature search.

ID	Reference
1	Comin et al. (2023)
2	EFSA (2006)
3	EFSA AHAW Panel (2013a)
4	EFSA AHAW Panel (2013b)
5	EFSA AHAW Panel (2015)
6	EFSA AHAW Panel (2017)
7	EFSA AHAW Panel (2021)
8	Gerritzen and Raj (2009)
9	Gibson et al. (2012)

TABLE A.1 (Continued)

ID	Reference
10	Grandin (2014)
11	Gregory et al. (2006)
12	Grist et al. (2018a)
13	Grist et al. (2018b)
14	Llonch et al. (2015)
15	Mason et al. (2018)
16	Rodriguez et al. (2016)
17	Sanchez-Barrera et al. (2014)
18	Tetlow et al. (2022)

APPENDIX B

Protocol for the development of the opinion

The protocol for the subquestions of the assessment that will be addressed using the LOW extent of planning (according to the EFSA guidance on protocol development) using expert opinion is summarised in Table B.1 of this Appendix. The protocol for the subquestions addressed using literature reviews is summarised in Table B.2 of this Appendix.

TABLE B.1 Protocol for subquestions that will be addressed using expert opinion using the LOW extent of planning.

	Subquestion			
	Identification of highly relevant welfare consequences (WC) (subquestion 2a)	Identification of ABMs for relevant WC (subquestion 3a)	Identification of hazards for relevant WC (subquestion 4a)	Identification of preventive and corrective measures (subquestion 5a)
Formulation of subquestion	For phase 1 (handling, moving and restraint): To identify the highly relevant WCs considering the severity, duration and frequency of occurrence for each of the previously defined animal killing practices per animal category For phase 2 (killing): No identification needed as the focus is on pain and fear	To generate a list of ABMs for the highly relevant WC Only those ABMs that are feasible during killing will be included	To generate a list of hazards leading to each identified welfare consequence	To generate a list of measures to prevent or correct the identified hazards or WCs
Definition of the approach	Individual classification of WCs in terms of relevance and group discussion to identify the highly relevant ones by consensus	A group discussion within the EFSA experts and hearing experts selected	A group discussion within the EFSA experts and hearing experts selected	A group discussion within the EFSA experts and hearing experts selected
Identification of experts	Expert profile: researchers with field experience and specialised in animal slaughter and killing scenarios, welfare consequences, animal-based and resource-based measures. Diplomates in animal welfare, behaviour and other veterinary science topics	See expert profile subquestion 2a	See expert profile subquestion 2a	See expert profile subquestion 2a
Preparation of the evidence dossier	No evidence dossier is needed, and judgement is based on the expertise of the consulted experts	No evidence dossier is needed, and judgement is based on the expertise of the consulted experts	No evidence dossier is needed, and judgement is based on the expertise of the consulted experts	No evidence dossier is needed, and judgement is based on the expertise of the consulted experts
Methods of synthesis of individual expert estimates and their uncertainty	Classification of WCs into four categories (highly relevant – the target, moderately relevant, slightly relevant and non-applicable) Uncertainty analysis performed on key conclusions	Only the agreed list of ABMs is kept Uncertainty analysis performed on key conclusions	Only the agreed list of hazards kept Uncertainty analysis performed on key conclusions	Only the agreed list of measures is kept Uncertainty analysis performed on key conclusions

TABLE B.2 Protocol for subquestions that will be addressed using literature review using the LOW extent of planning.

	Sub-question				
	Description of current practices and housing systems (subquestion 1)	Description of relevant welfare consequences (WC) (subquestion 2b)	Description of ABMs for relevant welfare consequences (WC) (subquestion 3b)	Description of hazards per relevant WC (subquestion 4b)	Description of preventive and corrective measures (subquestion 5b)
Formulation of subquestion	To provide a description of the main current killing practices	To describe the highly relevant WC	To describe the ABMs for the highly relevant WC	To describe all hazards leading to the identified highly relevant welfare consequences	To describe preventive and corrective measures to prevent the identified hazards
Eligibility criteria for study selection	Literature describing current killing practices The language: English	Literature describing the highly relevant welfare consequences	Literature describing ABMs for the highly relevant welfare consequences	Literature describing hazards and their relationship with the highly relevant welfare consequences	Literature describing preventive and corrective measures for the identified hazards or WCs
Search strategy	Previous EFSA scientific outputs complemented with recent studies published in peer-reviewed and grey literature describing killing practices The screening is performed by one reviewer	Previous EFSA scientific outputs complemented with recent studies published in peer-reviewed and grey literature describing the highly relevant WC The screening is performed by one reviewer	Previous EFSA scientific outputs complemented with recent studies published in peer-reviewed and grey literature describing the ABM related to the highly relevant WC The screening is performed by one reviewer	Previous EFSA scientific outputs complemented with recent studies published in peer-reviewed and grey literature describing the hazards related to the highly relevant WC The screening is performed by one reviewer	Previous EFSA scientific outputs complemented with recent studies published in peer-reviewed and grey literature describing preventive and corrective measures The screening is performed by one reviewer
Methods for study inclusion/exclusion	Publications that are not considered relevant nor providing any additional value to address the question will be removed	Same as in subquestion 1	Same as in subquestion 1	Same as in subquestion 1	Same as in subquestion 1
Methods for extracting data from included studies	Qualitative information related to the main killing practices will be extracted by one expert (one reviewer)	Qualitative information on the relevant welfare consequences will be extracted by one reviewer	Information on the use of the ABM to assess the welfare consequence, including, when possible, qualitative information on sensitivity, specificity and feasibility of the ABM	Qualitative information on the relevant hazards related to the selected welfare consequences will be extracted by one reviewer	Qualitative information on the preventive and corrective measures for the identified hazards will be extracted by one reviewer
Methods for appraising evidence	Relevance of the evidence will be assessed qualitatively after reading of abstracts and, if a paper is selected, the full-text document is taken into account for the assessment	Relevance of the evidence will be assessed qualitatively after reading of abstracts and, if a paper is selected, the full-text document is taken into account for the assessment, if the application of a correct methodology used to describe WCs (using ABMs) and hazards related to WCs is reported	Same as in subquestion 2b	Same as in subquestion 2b	Same as in subquestion 2b

TABLE B.2 (Continued)

	Sub-question				
	Description of current practices and housing systems (subquestion 1)	Description of relevant welfare consequences (WC) (subquestion 2b)	Description of ABMs for relevant welfare consequences (WC) (subquestion 3b)	Description of hazards per relevant WC (subquestion 4b)	Description of preventive and corrective measures (subquestion 5b)
Preliminary identification and prioritisation of sources of uncertainty	Main sources of uncertainty will be identified based on the appraisal of the scientific literature and the working groups experts' knowledge on the killing practices. For the selection of transport scenarios, WCs, ABMs and hazards, there is still a risk of missing important issues. This is excluded as much as possible by selecting wide range of welfare experts in working groups and task force welfare, but a full quantification of the uncertainty has not been carried out at this stage	Main sources of uncertainty will be identified based on the appraisal of the scientific literature and the working groups experts' knowledge on the killing practices, welfare consequences, ABMs and hazards	Same as in subquestion 2b	Same as in subquestion 2b	Same as in subquestion 2b
Methods for synthesising the evidence	Evidence is synthesised qualitatively through a narrative text	Same as in subquestion 1	Same as in subquestion 1	Same as in subquestion 1	Same as in subquestion 1
Methods for analysing uncertainties individually and combined	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

APPENDIX C

Sources of uncertainty

Source of uncertainty	Nature or cause of the uncertainty	Impact of the uncertainty on the assessment
Expert group – number & type of experts	A limited number of experts (4) were selected based on subject (on-farm killing) and this may have resulted in a bias in the assessment processes	The number of highly relevant welfare consequences (WC), ABMs and/or hazards may have been over or underestimated
Methodology for selection of highly relevant welfare consequences (per each killing phase/practice)	The selection of highly relevant welfare consequences per each killing phase and practice was achieved by expert knowledge elicitation for which a predefined scale of relevance was used	The WCs selected as highly relevant may have been underestimated or overestimated (a welfare consequence selected might have been included in error and similarly another welfare consequence might have been excluded in error)
Extensive literature search – Language	The search was performed exclusively in English (at least the abstract for other languages). More studies could have been identified by including references with abstracts in languages other than English	The number of ABMs and/or hazards may have been underestimated
Extensive literature search – Publication type	Studies considered included primary research studies identified through the extensive literature search and grey literature (factsheets, guidelines, conference papers, EU reports, book chapters, etc.) known to the EFSA experts, but an extensive search of the grey literature was not conducted. Therefore, there may be reports (grey literature) and other guidance documents on animal welfare of which the Working group is not aware of	The number of ABMs and/or hazards may have been underestimated
Extensive literature search – Search strings	Although the search criteria were clearly reported, some synonyms may have not been used in the search strings, and thus less hits might have been retrieved	The number of ABMs and/or hazards may have been underestimated
Extensive literature search – Source of studies	The search was limited to Web of Science Core Collection and four more specialist/subject-specific databases (AGRICOLA, AGRIS, CABI - Animal Health & Production Compendium and MEDLINE). Although the search was complemented by internet searches and manual searches of the publicly available literature, no data were retrieved from other sources (e.g. industry data). More information could have been retrieved by applying a different methodology (e.g. public call for data)	The number of ABMs and/or hazards may have been underestimated
Extensive literature search – inclusion and exclusion criteria	A conservative approach was applied during the screening phase that could have led to the exclusion of certain studies that could have included relevant information	Underestimation of the published relevant papers and existing information. The number of ABMs and/or hazards may have been underestimated
Animal species and animal categories considered in the studies retrieved in the literature search	The animal species or categories used in the studies retrieved might not be the breeds/strains or categories currently used in the EU to study WCs and ABMs, thus requiring an extrapolation exercise from the experts	Underestimation of the level of magnitude of the WCs and related ABMs Overestimation of the level of magnitude of the WCs in case the retrieved papers are specifically pointing to a specific animal category and/or species
Killing practices in the studies retrieved in the literature search	The studies retrieved through the literature search could have been performed anywhere in the world, and thus may consider killing conditions different from those currently allowed in the EU, also regarding animal welfare. Thus, experts had to extrapolate findings to the EU relevant conditions in some cases	Underestimation/overestimation of the level of magnitude of the WCs and related ABMs