TECHNICAL REPORT submitted to EFSA

Project to develop Animal Welfare Risk Assessment Guidelines on Stunning and Killing[1]

Prepared by

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Contents

1. Glossary

Exposure Assessment
The quantitative and qualitative evaluation of the likelihood of hazards to welfare occurring in a given calf population.

Hazard
Any factor, occurring from birth to slaughter, with the potential to cause an adverse effect on calf welfare.

Hazard characterisation
The qualitative and quantitative evaluation of the nature of the adverse effects associated with the hazard. Considering the scope of the exercise of the working group the concerns relate exclusively to calf welfare.

Hazard Identification
The identification of any factor, from birth to slaughter, capable of causing adverse effects on calf welfare.

Hazard magnitude
The combination of intensity and duration of adverse effects.

Risk
A function of the probability of an adverse effect and the severity of that effect, consequent to a hazard for calf welfare.

Risk Characterisation
The process of determining the qualitative or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse effects on welfare in a given calf population based on hazard identification, hazard characterisation, and exposure assessment.

Unaltered remain the following CAC (Codex Alimentarius Commission) definitions (Note: for completeness ALL definitions used by CAC - while not necessarily used in this document - have been included):

Quantitative Risk Assessment
A risk assessment that provides numerical expressions of risk and an indication of the attendant uncertainties (stated in the 1995 expert consultation definition on risk analysis). Reference

Qualitative Risk Assessment

A risk assessment based on data which, while forming an inadequate basis for numerical risk estimations, nevertheless, when conditioned by prior expert knowledge and identification of attendant uncertainties, permits risk ranking or separation into descriptive categories of risk.

Risk Analysis
A process consisting of three components: risk assessment, risk management and risk communication.

Risk Assessment
A scientifically based process consisting of the following steps: i) hazard identification, ii) hazard characterisation, iii) exposure assessment and iv) risk characterisation.

Risk Communication
The interactive exchange of information and opinions concerning the risk and risk management among risk assessors, risk managers, consumers and other interested parties.

Risk Estimate
Output of risk characterisation.

Risk Management
The process of weighing policy alternatives in the light of the results of risk assessment and, if required, selecting and implementing appropriate control options (i.e. prevention, elimination, or reduction of hazards and /or minimization of risks) options, including regulatory measures.

Sensitivity Analysis
A method to examine the behaviour of a model by measuring the variation in its outputs resulting from changes to its inputs.

Transparent
Characteristics of a process where the rationale, the logic of development, constraints, assumptions, value judgements, decisions, limitations and uncertainties of the expressed determination are fully and systematically stated, documented, and accessible for review.

Uncertainty Analysis
A method used to estimate the uncertainty associated with model inputs, assumptions and structure/form.

2. Introduction

In December 2005 an EFSA scientific Colloquium "Principles of Risk Assessment of Food Producing Animals: Current and Future Approaches" was held in Parma presenting and discussing the state- of- the- art regarding the Risk Assessment (RA) of food producing animals. In one of the conclusions it was stated that "no specific standardized methodology exists in the field of the Animal Welfare Risk Assessment".

In several EFSA reports adopted by the panel for Animal Health and Animal Welfare (AHAW) approaches to animal welfare RA's have been presented. In a more formalized way such RA's have to date been conducted and published for the welfare of calves ["The risks of poor welfare in intensive calf farming systems" (EFSA 2006)], pigs ["Scientific Report on animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and un-weaned piglets" (EFSA 2007), "Scientific Report on welfare and disease in fattening pigs in relation to housing and husbandry" (EFSA 2007), "Scientific Report on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems" (EFSA 2007)] , seals [Animal Welfare aspects of the killing and skinning of seals;
Scientific Opinion of the Panel on Animal Health and Welfare" (EFSA 2007)] and, finally, for farmed Atlantic salmon ["Scientific Opinion on animal welfare aspects of husbandry systems for farmed Atlantic salmon (EFSA, 2008)]. In June 2007 an EFSA workshop was held in Vienna to assemble experiences from the past and ongoing Animal Welfare Risk Assessments with the primary purpose of identifying weaknesses of the various approaches and suggesting improvements. At the workshop the major issues addressed included the following:

- How to deal with cumulative effects of- or interaction between (simultaneously occurring) factors.
- How to more accurately assess exposure assessment scores (particularly in cases where insufficient documented data are available) and how to value the performance of experts and consultants for this purpose.
- Is death (or death rate) in itself a welfare issue? Does it serve to indicate that production systems are inadequate or (more controversially) does it represent the end-point of a long life cycle with poor- against a short one with adequate welfare? A better description of death (or consciousness and sensibility during dying) as an adverse effect is needed.
- How to deal with situations in which promoting animal welfare would compromise the prevention of animal disease and/or food safety.
- Which welfare indicators (animal- or production factor-based) are practicable? Do these suitably reflect the actual welfare of the animal? Can they be combined?
- How can positive factors (i.e. adhering to Good Practices or introducing targeted additional measures) improve (or compensate for suboptimal) welfare when hazards (such as poor housing or health) prevail?
- Can a generic methodology for the RA of animal welfare that would ensure transparency, validity and reliability of the process, be identified?
- If the latter applies, can the useful elements of the *ad hoc* approaches relied on to date be merged into a 'generic' model that would assure a systematic approach to assessing the risks to animal welfare?

The EFSA AHAW panel has recently published a document on the "state- of- the- art" in Risk Assessment in Animal Welfare (Opinion of the Scientific Panel on Animal Health and Welfare on a self mandate on the Framework for EFSA AHAW Risk Assessments, The EFSA Journal, 2007). A major conclusion of this opinion was that in order to assess the risks of poor animal welfare, adverse consequences should be measured directly on the animals (e.g. lameness in cows). Hence, RA should rely on data derived from animal based welfare assessments. Although, a large body of qualitative data (often transferred into a semi-quantitative analysis using scores) is available for such parameters, one must confront the fact that quantitative data are rather scarce.

Different conditions on farms, in fields, at abattoirs, in the laboratory and in emergencies can determine the choice of methods for stunning and killing of animals. Therefore, depending on the method used and the prevailing circumstances, different welfare assessment criteria can be applied for the period in question. Until now, however, no Risk Assessment of Animal Welfare during stunning and killing has been formally applied.

This is the final report describing a RA working methodology for Animal Welfare related to stunning and killing issues. The task of the WRAPSTUN team was to define the various stunning and killing procedures used in farm, slaughter, experimental and wild animals and to identify the associated animal welfare hazards. A significant part of the process was to suggest 'generic' procedures for animal welfare risk assessment that would sufficiently address the problem areas described above and at the same time providing guidelines for future Animal Welfare Risk Assessment in general.

Existing information on the stunning and killing methods used in food producing and laboratory animals are described taking into account the previous EFSA reports on the subject. In addition, an overview of risk assessment methodologies in animal welfare previously applied by EFSA working groups is presented, addressing the merits, disadvantages and limitations of each approach.

2.1. Animal welfare as related to stunning and killing

The fact that killing animals for human consumption is generally accepted in Europe forms the starting point of this work. Consequently, the project does NOT aim to consider the welfare effects of killing as compared to not killing, instead focuses on the most appropriate methods of stunning and killing and relevant indicators to be used for assessing the risks and ultimately safeguarding, animal welfare.

Animal welfare has been defined in various ways in the scientific literature (e.g. Kiley-Worthington, 1989; Broom, 1996; Duncan 1996). The concept, being relevant to all vertebrates, is a characteristic of an individual animal and concerned with the effects of its genotype aspects and environment as well as their interactions. Most general definitions indicate that good welfare occurs when the animal is in harmony with its environment. Although it is generally recognised that feelings of the animal are most important for animal welfare, there is still some controversy as to whether welfare should ultimately be defined in terms of the animal's emotions and feelings only or in terms of its biological functioning and state with regard two attempts to cope (Fraser, 2004; Fraser, 2008).

When conducting risk assessment of animal welfare as related to stunning and killing, the choice of parameters is dependent on the selected starting point in the slaughter or killing process. For example, if transport to slaughter, lairage or temporary housing before slaughter, handling and restraint before stunning, or chasing before killing of game are included in the assessment, the parameters must not only account for the animal's welfare in the period from stunning to death, but should also address difficulties for the animal in coping with the environment (and with possible frustration, hyperthermia, hunger or thirst, lameness, injuries, infectious diseases, etc.) in the preceding period. Thus, there are several alternatives:

One approach is to restrict the risk assessment of animal welfare to the period (i) from when stunning is applied, if we include religious slaughter, (ii) from when the animal is restrained for killing without preceding stunning, or if we include game hunting, (iii) from when the animal is shot to the moment of death. Alternatively, one could consider the period (j) from when driving to the stun box (or corresponding device/area) starts, if we include religious slaughter, (jj) from when the driving to the killing box (or corresponding stage/area) starts, or if we include game hunting, (jjj) from when the hunt starts, to the point of death.

During the restricted period from stunning (or being shot as in game animals) to death, the main issues relevant to the animal's welfare are negative emotions like distress, fear, pain and suffering, and the time during which such emotions are experienced. Obviously, effective stunning prevents experience of such emotions since the animal will immediately become unconscious.

In two reports on welfare aspects of stunning and killing methods for commercial animal species (EFSA, 2004; 2006), the EFSA AHAW panel presented the scientific basis of consciousness and stunning describing the main stunning and killing methods in commercial slaughterhouse- or on-farm practices in Europe, and recommended procedures appropriate to the species with minimum requirements such that unconsciousness and insensibility is induced without causing avoidable pain, suffering and distress. For instance, although the reports recognised that transport to the slaughterhouse, lairage conditions, pre-slaughter handling and restraint prior to stunning may cause serious welfare problems, itconcentrated on the point of application of the stunning and stun/killing techniques, disregarding preceding or subsequent procedures. In a later report on the killing and skinning of seals (EFSA, 2007), animal welfare was assessed from the perspective of avoidable or unnecessary pain and distress during the hunt.

When managing animal welfare risks in connection with stunning and killing, the extent to which reduced welfare can be avoided must be considered in relation to practical, ethical, social, economical, cultural or religious limitations. An evaluation of such limitations might also be seen as part of animal welfare risk assessment. However, this report is restricted to criteria and methods of assessment based solely on scientific evidence of animal welfare measures, with limited regard to what is feasible under specific practical conditions.

Definitions of welfare can hardly be defended scientifically. Instead, they are formulated on the basis of the context and on the goals one wants to achieve. Regardless of the definition chosen, there will be alternative views on what is an appropriate definition. However, some definitions are more useful than others in a scientific context. From a risk management and communication perspective, the choice should also match the opinion of most people, or at least be understandable and acceptable.

For the purpose of this project, we defined the welfare of an animal in accordance with the definition made by Broom. Broom (1986) defines it as follows: "the welfare of an animal is its state as regards its attempts to cope with its environment". Welfare therefore includes the extent of failure to cope, which may lead to disease and injury, but also of the ease of coping or difficulty in coping. Furthermore, welfare includes pleasurable mental states and unpleasant states such as pain, fear and frustration (Duncan 1996, Fraser and Duncan 1998). Coping means having control of mental and bodily stability and, consequently, stretches continuously from 'good' to 'bad'.

3. Stunning and killing methods for food producing and laboratory animals

3.1. Introduction

Welfare aspects of stunning and slaughter of meat animals as well as quality implications have been reviewed extensively in several publications as listed below. However - as this review is intended as a basic reference document for the subsequent risk assessment - only a limited number of relevant references will be used. Furthermore, emphasis is also given on the conventional and novel methods commonly used. Although, there exist several unusual and unconventional methods employed due to lack of facilities in certain parts of the world such as drowning pigs in baskets and freezing other species, these have been excluded because of their welfare unacceptability. In addition, aspects of lack of proper back-up stunning systems are disregarded here as a proper access to such are considered representing 'best practice' for all stunning systems.

Each stunning technique assessed in hazard and risk assessment tables is assumed to be capable of being applied correctly under normal circumstances. Optimum application parameters for each species such as tong and gun positions, voltage and amperage levels, cartridge strength/size (as colour codes), gas concentrations and duration of application exist in various documents. These include national legislative documents, good practice guidelines and codes of practice as well as manufacturers' recommendations contained in manuals. As a general rule, the following can be given as examples of correct stunning:

- Electrical stunning: pigs 1.3 A, sheep 1 A, broilers 100 mA, cattle 2 A; 1-3 s duration.
- Captive bolt: appropriate colour code for each species and size.
- Carbon dioxide: pigs >70%; 60 s duration.

Recently published review documents on stunning, slaughter and killing methods include European Community (1993), EFSA (2004, 2005) and OIE (2005a, 2005b).

4. The Development of a practicable ‘generic’ Risk Assessment methodology for Animal Welfare

4.1. Introduction

Risk analysis in the proper sense of the concept includes 3 components, i.e. Risk Assessment (RA), Risk Management (RM) and Risk Communication (RC). These three elements are not necessarily addressed by one and the same actor or faction. Within the European Union risk analysis of food production (including foods of animal origin) is the joint responsibility of the European Food Safety Authority (addressing RA and RC) and the European Commission (addressing RM). Whereas RA is a widely used term in the areas of epidemiology and food safety (for which tried and commonly accepted methodologies have been established), its application in the area of animal welfare is relatively new and the development of appropriate methodologies is still “work in progress”.

The objective of risk assessment is to identify and characterize potential hazards (e.g. to human health or animal welfare or to food safety), to estimate the probability and magnitude of adverse effects resulting from exposure to those hazards and to determine the resulting risks.

Risk assessment should be science-based, well documented, objective, repeatable, transparent and open to review. These principles are fundamental to substantiate its outcome.

- **Science-based**: the process should be based on the best available evidence, i.e. on results that have been obtained by relying on recognized scientific methods.
- **Well-documented**: i.e. it should be assured that all available scientific information is considered and kept available for review.
- **Objective**: i.e. the problems to be addressed in RA should be clearly stated.
- **Repeatable**: i.e. a group of experts other than the one engaged in RA should on the basis of the information compiled reach the same conclusions.
- **Transparen**t: The methodologies and data used for RA should be clearly documented and uncertainties should be clearly identified and taken into consideration in the final assessment.

Risks are preferably assessed quantitatively (provided enough data are available), semi-quantitatively (when data are rather scarce) or qualitatively (in absence of quantitative data). Though still useful for purposes of risk communication and -management, the outcome of a qualitative risk assessment is inevitably more subjective.

4.2. A brief overview of the various methods used to date and their limitations

In responding to various requests from the European Commission, EFSA has over the past few years issued a number of scientific opinions on animal welfare issues and for this purpose commissioned their Animal Health and Animal Welfare (AHAW) panel to form working groups that included - besides experts on animal welfare - scientists with a background in RA. In this section we summarize 4 approaches to RA (3.2.1 through 3.2.4) documented in 6 scientific opinions that - to date – have been published and indicate the limitations of each approach.

4.2.1. The risks of poor welfare in intensive calf farming systems (EFSA, 2007)

The approach was based on the *codex alimentarius* guidelines, i.e. including Hazard Identification, Hazard Characterization, Exposure Assessment and Risk Characterization.

Guided by a list of 'needs of animals', all production factors to which calves (held under defined husbandry conditions in Europe) are subjected and which may represent a hazard to their welfare were identified, characterized in terms of severity the latter to be assigned with a severity score (HC in the final calculation; see below). Subsequently the working group estimated the exposure of the entire European calf population held under the defined production systems, cross-checked these estimations with a consultation group of field experts (see below) with the aim to reach a consensus opinion on exposure assessment (EA) scores. Then a risk estimate score (RE) was calculated (RE = HC x EA). The analysis, carried out separately for nine different production options was qualitative and the risks associated with each hazard were classified as 'negligible', 'minor' or 'major'. When published data were absent or considered insufficient to allow risk estimation, risks were classified as 'uncertain'. Executive summary charts provided graphical, more quantitative presentations for the scores of each production system.

Hazard identification
The relation between the hazards and impaired needs were listed in a table. Possible interactions between hazards were not considered.

Hazard characterization (HC)
The characterization of the impact of the hazards on the animal welfare was based on a 5-point qualitative scale (Table 4.1) ranging from 'slight adverse effect' to 'very serious effect'. The classification was based on expert opinion substantiated where possible by published records.

Table 4.1. Hazard characterization score.

Evaluation	Code	Score	Explanation
Hazard characterisation	SA	1	Slight Adverse Effect
	AE	2	Adverse Effect
	MS	3	Moderately Serious
	SE	4	Serious
	VS	5	Very Serious

Exposure assessment (EA)
The exposure (% of the population exposed to a given hazard) was scored on a 5-point scale from 'very rare' to 'very frequent' based on a quintile division (i.e. increments of 20%; Table

4.2). This was done by reaching consensus after consultation of an expert group of independent veterinarians with experience in the various husbandry systems practiced in different European countries.

Table 4.2. Exposure assessment scores.

Evaluation	Code	Score	Explanation
Exposure assessment	VR	1	Very rare (1 to 20%)[1]
	RA	2	Rare (21 to 40%)
	MF	3	Moderately Frequent (41 to 60%)
	FR	4	Frequent (61 to 80%)
	VF	5	Very Frequent (81 to 100)

[1]; 0 is considered not applicable

Risk Estimation and characterization

The risk for poor welfare was estimated by multiplication (HC x EA) yielding a risk estimate score which was subsequently qualitatively expressed by integrating both the hazard characterization and the exposure assessment using a classification matrix (Table 4.3), generating a qualitative score ranging from ‘negligible risk’ to ‘major risk’. Criteria were set by multiplying scores 1-5 for HC and 1-5 for EA to ‘negligible’ for scores 1-8, ‘minor’, 9-16, and ‘major’ for 20-25.

Table 4.3. Risk classification matrix.

	Very rare (1-20%)	**Rare (21-40)**	**Moderately frequent (41-60%)**	**Frequent (61-80%)**	**Very frequent (81-100%)**
Slight adverse effect	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk
Adverse effect	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Minor risk
Moderately serious effect	Negligible risk	Negligible risk	Minor risk	Minor risk	Minor risk
Serious effect	Negligible risk	Negligible risk	Minor risk	Minor risk	Major risk
Very serious effect	Negligible risk	Minor risk	Minor risk	Major risk	Major risk

Uncertainty and variability

When insufficient data were available for the exposure assessment, the risk was characterized as uncertain and when not enough data were available to support the view that a certain factor would constitute a hazard these were not further considered.

Weaknesses/limitations of the approach - summarized

- Does not allow for variation in severity or exposure (inherent to classification).
- Descriptors in classification tables not transparent (open for interpretation).
- Quality (reliability) and availability of (published) data not considered.

- No Uncertainty Analysis in HC (based on quality of published or expert data); In EA mere indication of presence-or-absence of uncertainty.
- Duration of adverse effects were not separately scored but considered in the HC (severity score).
- As a consequence of HC and EA scores being discrete the Risk Estimate (HC x EA) scale is discontinuous (remedied by designing a Risk outcome matrix).

4.2.2. Pig welfare risk assessment (EFSA 2007a; 2007b; 2007c)

Three similar RA's were conducted following the approach and nomenclature formulated in the *codex alimentarius* guidelines. For each step of the process, experts in the working groups were asked to individually fill out the tables (see Annex 1) for each target population, based on current scientific knowledge and published data. Their scores were compared and if there was disagreement, further data collection efforts were made (by reviewing the scientific literature and compilation of exposure data from questionnaires sent to field experts in Europe) to allow coming to a consensus opinion.

The experts were divided in groups each conducting separate RA's for different target groups, (i.e. Sows and Boars, Fattening pigs (considering their life cycle, Outdoor vs Indoor production system), thereby distinguishing between either the life stage of the animals (Sows and boars and fattening pigs report), production- (outdoor vs. indoor holding in fattening pigs report) or on management-system (docked vs. undocked pigs in tail-biting report).

Hazard identification
Same procedure as described for calf welfare under 4.2.1.

Hazard characterization
For each hazard a quantitative estimate of its adverse effect on the welfare of the individual animal *("magnitude"*) was estimated, for which purpose both its "*severity"* (expressed by a score indicating the animal's physiological/behavioural response; Table 4.4) and its *"duration"* (expressed in days) were separately considered.

Table 4.4. Severity scores of the adverse effects.

Severity of the adverse effect	Descriptive definition	Score
Critical	Fatal, death occurs either immediately or after some time	4
Severe	Involving explicit pain, malaise, frustration, fear or anxiety Strong stress reaction, dramatic change in motor behaviour, vocalization may occur	3
Moderate	Some pain, malaise, frustration, fear or anxiety Stress reaction, some change in motor behaviour, occasional vocalization may occur	2
Limited	Minor pain, malaise, frustration, fear or anxiety Physiological effects may be recorded as well as moderate behavioural changes	1
Negligible	No pain, malaise, frustration, fear or anxiety	0

In addition the *"likelihood"* [i.e. the probability of the individual animal suffering the adverse effect of a hazard, assuming exposure to a given scenario and expressed as %] was estimated and minimum, most likely and maximum values for duration of the effect indicated. Precise information on the latter was hardly available from literature, and so these ranges were generally provided by the experts as estimates that served as parameters of a Beta-Pert distribution expressing their uncertainty.

The numerical score characterizing the hazard was calculated as follows:

Magnitude = (Severity score/4) x Duration (in days)

Exposure assessment

For each of the factors, the probability (in %) of the animal target population in Europe being exposed to the hazard at a defined intensity and duration, was expressed as minimum, most likely and maximum values.

Risk characterization

The numerical score estimating the risk of each hazard expresses the welfare burden for the animal target population in Europe. It was calculated as follows:

Risk Estimate = Magnitude x Likelihood of Effect x Probability of Exposure

Uncertainty and variability

The uncertainty (i.e. both that related to the 'likelihood of effect prevailing in an individual animal' and to the 'probability of the target population being exposed') was expressed qualitatively (via scoring the availability and reliability of literature or exposure data as shown in Tables 4.5 and 4.6) and quantitatively (by indicating the ranges of the risk estimates).

Table 4.5. Qualitative uncertainty scores for the likelihood and exposure.

Low	Solid and complete data available; strong evidence provided in multiple refs; authors report similar conclusions
Medium	Some but no complete data available; evidence provided in small number of refs; authors' conclusions vary from one to other; solid and complete data available from other species which can be extrapolated to the species considered
High	Scarce or no data available; rather evidence provided in unpublished reports, based on observations or personal communications; authors' conclusions vary considerably between them

Table 4.6. Uncertainty Classification matrix.

Likelihood uncertainty \ Exposure uncertainty	High	Medium	Low
High	High	High	High
Medium	High	Medium	Medium
Low	High	Medium	Low

Weaknesses/limitations of the approach - summarized

- Descriptors in classification tables not transparent (open for interpretation)
- Formula for magnitude assumes linearity of the severity scores;
- In EA the intensity could only be expressed by the presence-or-absence of the factor. Only rarely could the hazard be defined quantitatively (e.g. concentration of ammonia in the range 25-49 ppm); partly remedied through introducing specific exposure scenario's describing defined combinations of EA intensities and durations.
- In HC, both the uncertainty about severity and duration of the adverse effect not taken into account (not included in the tables)

4.2.3. Animal welfare aspects of the killing and skinning of seals (EFSA 2007d)

Description of major scenarios

Major practices for catching and killing seals (i.e. using nets, physical methods or firearms) were identified. The likely chain of events – and the associated inherent hazards to welfare - was described in various scenarios (in the report termed 'risk pathways') for each of which RA was conducted. A total of 11 scenarios' (also taking account of different weather and/or habitat conditions) were considered. As the number of publications on the issue was very limited the assessment primarily relied on data provided by a small number of experts and consequently the methodological approach was largely qualitative. For this reason expressing RA parameters in numerical or graphic terms was abandoned.

Hazard identification

The hazards related to stunning, killing and skinning of seals were listed for each scenario. Interactions between hazards were not considered.

Hazard characterization

The magnitude of the adverse effect was assessed relying on classifications of the severity (termed ‘intensity’ in the report) and duration, using 4-point scales for both. For severity (intensity) and duration, qualitative descriptions and quantitative time scales were used, respectively (Tables 4.7 and 4.8).

Table 4.7. Severity (‘Intensity’) and duration scales used in the HC of seal killing/skinning.

Evaluation	Code	Category
Hazard characterization – Intensity (intensity of the adverse effect - recognition of pain and distress)	Se	Severe
	Mo	Moderate
	Mi	Mild
	Ne	Negligible
Hazard characterization – Duration (duration of the adverse effect)	4	>1 min
Physical methods and firearms	3	30-60 sec
	2	5-30 sec
	1	<5 sec
Netting	4	>30 min
	3	15-30 min
	2	5-15 min
	1	<5 min

In view of published data being hardly available, the magnitude of the effect was not numerically expressed but classified using the classification matrix in Table 4.8.

Table 4.8. Categories of magnitude of adverse welfare effect based on duration and severity (intensity) of adverse welfare effects used in seals risk assessment.

Magnitude of adverse welfare effect		**Duration of adverse welfare effect**			
		4	**3**	**2**	**1**
Intensity of adverse welfare effect	**Severe**	Major	Major	Moderate	Moderate
	Moderate	Major	Moderate	Moderate	Minor
	Mild	Moderate	Moderate	Minor	Minor
	Negligible	Moderate	Minor	Minor	Negligible

Exposure assessment

Exposure was ranked in 4 classes: “Very unlikely”, “Likely”, “Unlikely“, “Very likely”.

Risk characterization

Rather than expressing risks in numerical or descriptive terms, they were characterized by merely presenting the magnitude and the likelihood of a given adverse effect. Since most of the data resulted from expert opinion, disagreements among experts were accounted for by listing the lower and upper limits of their estimates. When factors like weather and habitat were considered to affect the likelihood of a given adverse effect, those scenarios were presented.

Uncertainty and variability
Uncertainty was classified relying on Table 4.9. In a report annex including the tables with the scores of the various experts two measures of uncertainty were identified, i.e. availability and the reliability of the data source.

Table 4.9. Data source scores used in seals risk assessment.

Data source score	Definition
3	Scarce or no data available; unpublished data or opinion; expert opinion
2	Technical opinion; peer reviewed publications with contradictory results; non-peer reviewed publication; some but incomplete data; comparative data from other species
1	Solid and complete data available; international peer reviewed publication

Weaknesses/limitations of the approach – summarized

- Fully applying the improved RA model was not considered [possibly for reasons of lack of data (see below)] allowing little if any quantification
- Very restricted availability of published quality data and of experts, which generated high uncertainties
- The terms with which severity (‘intensity’) was described in HC are not transparent (open for interpretation); it was merely stated that they were based on pain and distress recognition. Note that the original term severity was changed into intensity.
- The descriptors for the EA classification were not defined
- The criteria by which uncertainty should be classified were lacking

4.2.4. Animal welfare aspects of husbandry systems for farmed Atlantic salmon (EFSA, 2008)

This represents the first of a series of reports on the welfare of fish and has recently been adopted by EFSA’s AHAW panel. As was the case for seals, it was recognized that quantitative data related to production systems and effects are very limited so it was decided to follow a largely qualitative approach primarily relying on expert opinion. Five major groups of factors potentially impairing salmon welfare - i.e. environmental (biotic and abiotic), feed & feeding, husbandry, genetics, and, finally, the impact of disease and disease control measures - were ranked as to their priority in terms of representing risks and it was estimated which hazards are most important for each life stage to enable a comparison of the different production systems.

Life stages were not compared due to their different length.

The aim of the exercise was to rank the risk to allow prioritization of research needs and legal measures to be contemplated. As opposed to other RA's where these had already been considered, the effects of genetics were not taken into account since those effects are by definition life long.

The RA in salmon was carried similarly as those discussed before (hazard identification; hazard characterisation; exposure assessment and risk characterisation).

Experts were asked to score the different factors and scoring was then discussed within the panel.

The severity of the adverse effect was assessed as presented in Table 4.10. Scores were attributed according to scientific evidence of the level of physiological and behavioural responses.

Table 4.10. Severity of adverse effect.

Evaluation	Score	Explanation
Negligible	0	No pain, malaise, frustration, fear or anxiety as evidenced by measures of the normal range of behavioural observations, physiological measures and clinical signs for >95% of the species or strain/breed
Mild	1	Minor changes from normality and indicative of pain, malaise, fear or anxiety
Moderate	2	Moderate changes from normality and indicative of pain, malaise, fear or anxiety
Substantial	3	Substantial changes from normality and indicative of pain, malaise, fear or anxiety
Severe	4	Extreme changes from normality and indicative of pain, malaise, fear or anxiety, that if persist would be incompatible with life

The duration of the adverse effects were scored on a 0 to 100% scale considering the rest of the life of the fish and not just the particular life stage mentioned. The likelihood of adverse effects was scored as presented in Table 4.11.

Table 4.11. Likelihood of adverse effect occurring (i.e. proportion of population affected).

Evaluation	Score	Explanation
Negligible	0	The event would almost certainly not occur
Extremely low	1	The event would be extremely unlikely to occur
Very low	2	The event would be very unlikely to occur
Low	3	The event would be unlikely to occur
Moderate	4	The event would occur with an even probability
High	5	The event would be very likely to occur

The uncertainty value (low, medium and high), estimating the degree of confidence in the information, was not used in the calculation but as extra-information to describe the context (Table 4.12).

Table 1.12. Uncertainty.

Evaluation	Score	Explanation
Low	1	Solid and complete data available: strong evidence in multiple references with most authors coming to the same conclusions (e.g. in a meta-analysis).
Medium	2	Some or only incomplete data available: evidence provided in small number of references; authors' conclusions vary. Solid and complete data available from other species which can be extrapolated to the species considered.
High	3	Scarce or no data available: evidence provided in unpublished reports, or based on observation or personal communications; authors' conclusions vary considerably

The exposure assessment (frequency of exposure and the duration of the hazard) was scored according to Table 4.13.

Table 4.13. Frequency of exposure.

Evaluation	Score	Explanation
Negligible	0	The exposure would almost certainly not occur
Extremely low	1	The exposure would be extremely unlikely to occur
Very low	2	The exposure would be very unlikely to occur
Low	3	The exposure would be unlikely to occur
Moderate	4	The exposure would occur with an even probability
High	5	The exposure would be very likely to occur

Both the duration of the hazard as such (how long would the hazard prevail) as well as remaining after-effects were considered for the relevant life stage of the fish). For instance, whereas a predator attack might only last shortly, a temperature change of a longer duration might ensue. The duration of the hazard during a life stage was indicated in % (0% to 100%). In cases where a certain hazard would lead to instant death and would therefore rule out subsequent adverse welfare effects this was indicated. The latter is relevant, firstly because some risk scores may conflict with the reader's intuition (e.g. large mortality is also considered a welfare problem) and secondly to ensure comparability with other risk assessments.

Risk characterisation

For each hazard a semi-quantitative risk score for each life stage in all of the production systems employed during this life stage was calculated as follows:

Risk score = (severity of adverse effect) x (duration of the adverse effects) x (likelihood of adverse effect) x (frequency of hazard) x (duration of hazard)

The scores of frequency of hazard, severity and likelihood of effect were standardized to give even weighting to the scores (frequency of hazard/5, severity/4, and likelihood of hazard/5). Duration of hazard and duration of effect were divided by 100. Eventually, the risk score was multiplied by 100 to allow for their easier interpretation.

Uncertainty scores, not included used in the risk estimate calculation, were indicated in the final column. This also allows for indicating which areas need to be further researched. The two uncertainty scores for hazard characterization and exposure respectively were integrated in a single figure according to an uncertainty classification matrix (Table 4.14).

Table 4.14. Combined uncertainty scores.

		Uncertainty (exposure assessment)		
		High (3)	**Medium (2)**	**Low (1)**
Uncertainty (Hazard characterization)	**High (3)**	High (3)	High (3)	High (3)
	Medium (2)	High (3)	Medium (2)	Medium (2)
	Low (1)	High (3)	Medium (2)	Low (1)

Weaknesses/limitations of the approach

- Largely qualitative exercise inspired by the stated purpose of RA exercise, probably related with data availability (see below)
- Very limited number of quantitative and good data from literature or experts available
- Interaction between factors make RA difficult
- Different life stages with very different conditions make a "total" description of fish welfare difficult.
- A problem in scoring the "duration of adverse effect" arises when the animal dies as a consequence of a particular hazard. This can be described in two different ways depending on how the concept of "life time" is interpreted. (see next bullet point)
- It is virtually impossible to consider death as a primary welfare problem. If the adverse effect is fatal then the duration before death (i.e. an animal would not be subjected to suffering) would be the key welfare issue, even though death itself might indicate a primary welfare problem. If life time is considered as the "potential life time", rapid (or instant) death resulting from being exposed to a certain hazard has a very short (or practically no) duration. When defined in more absolute terms ('not being alive') the duration of the adverse effect (i.e. death) would be 100%. In the case of the fish welfare, it was decided to score the duration of the effect over the "potential life time" of the animal, but indicating if a hazard was so severe that it could lead to instant death.

4.2.5. Experiences and lessons learned from previous Risk Assessment excercises

The various approaches summarized above have largely been based on existing assessment methodologies published in Codex Alimentarius RA guidelines on food safety, after these were adopted for purposes of addressing animal welfare issues. The various risk assessors involved gradually improved the model taking into account as many elements of the afore-mentioned guidelines as - at the time - seemed feasible for the exercise.

Over the past few years a number of methodological problems were identified, some of a general nature (and consequently equally relevant for e.g. the epidemiology/food safety area), some inherently related to animal welfare RA. In the following these are discussed with a focus on those difficulties encountered in the latter

4.2.6. The relevance of formulating proper RA questions and appreciating the limitations of RA

Statement of purpose of the RA exercise

When authorities set out to develop effective strategies for the management of risks it is crucial that 'tailor-made' risk assessments become available. To allow for this it is paramount that risk managers carefully consider what exact purposes these RA's should serve so risk assessors can deliver a document addressing these essentials ["the better the question, the better the risk assessment" (Maijala, 2006)]. These purposes (essentials) are to be stated clearly in any RA document.

A clear definition of animal welfare components on which RA needs to be concentrated

In contrast with RM in the area of food safety, for which as a rule risks resulting from a single clearly defined hazard are assessed (e.g. *Salmonella* in one particular product, produced by a defined processing method in a specified production unit; see HACCP section] risk questions in the animal welfare area tend to be formulated less precisely. The concept 'welfare' encompasses various 'welfare components' that need to be addressed to secure successful assurance of overall welfare. In animal welfare terms these components are often associated with animal needs (see e.g. "The risks of poor welfare in intensive calf farming systems" (EFSA 2006)). If these needs are not satisfied this may result in, more or less serious, adverse welfare effects. Major adverse effects identified include: pain, distress, fear, anxiety, malaise, frustration, behavioural disorders. Consequently, from a methodological point of view, it is virtually impossible to calculate a single 'overall welfare' risk outcome, unless animal welfare experts could agree to integrate the various components in a mathematical function in which these are weighted. The latter is an important consideration for deciding which modelling approach is feasible (see the comments under 'linearity'; below). Although a similar issue was successfully dealt with in Welfare Quality by a large representation of EU welfare scientists it is unlikely that general consensus on such an approach can be reached within the community of animal welfare experts, it would be useful when risk managers indicate which of the welfare components is/are considered of overriding importance for their purpose.

A clear definition of the animal target population

Although the animal target population for which an RA is commissioned is usually indicated in general terms (e.g. calves, dairy cows, pigs, fish) one must realise that the hazards these species are subjected to vary for different husbandry systems, animal age groups, geographical regions/climatic conditions, etc. Consequently, when an RA for the entirety of Europe is to be conducted, the number of production options and associated scenarios that need to be considered will be substantial. Particularly where a (semi)quantitative approach to

RA is feasible in principle, this will inevitably lead to extremely time-consuming exercises, or, alternatively, to expert groups being discouraged to conduct these and instead rather being inclined to follow a more qualitative approach and/or restricting the number of production options (target populations) under scrutiny. Depending on the desired outcome risk managers are well-advised to take the latter into consideration

4.2.7. The necessity of building on previous RA experience

In the various RA exercises by EFSA at least one scientist with a background in risk assessment was included. From the relatively primitive approach followed in the calf welfare report gradually a more elegant RA model was developed that appears to be suitable for addressing many welfare RA exercises. To assure that such a growing 'generic' RA model is based on past experience it is essential that the various risk assessors are aware of the methodological problems already addressed and/or partly solved and remain involved in those with which newly attracted assessors are faced. Although there should remain room for the application of alternative approaches (particularly in situations where the data availability is limited), it appears counter-productive to allow risk assessments to be conducted without proper consideration of the already developed model or model variants.

Also, for reasons of transparency it would appear crucial that in further extending the methodology of welfare RA one relies on the existing terminology whenever possible and that before new terms are introduced these are carefully screened for correctness and/or compatibility with risk assessment approaches recommended by the responsible (CAC, OIE, IPPC).

4.2.8. The availability and quality of published data and experts

The reliability of the outcome of every RA is dependent on the quality of the data on which it is based. For reasons of transparency the information on hazards and their adverse effects are preferably to be found in the published literature, its reliability being dependent of the following parameters (prerequisites or preferable conditions in parentheses):

- Methods of generating data (scientifically accepted),
- Availability of species-specific data (i.e. relating to species addressed in RA),
- Completeness of data (all answers to relevant questions provided),
- Number of publications containing these data (multiple references),
- Solidity of data (in refereed 'quality' journals, recognised expert authors),
- Degree of consensus about data (similar conclusions in multiple references).

It should be noted that it would be helpful if agreement is found on what can be considered an adequate data base to allow a solid conclusion (how many publication can be considered 'multiple').

When data are scarcely available, of lesser quality, or have remained unpublished one must rely on the opinion of experts. Inherently, for less well-publicized themes only a limited number of scientists with knowledge of the area can be identified.

A quantitative analysis of uncertainty is based on consulting an uncertainty classification table. The experience gained in the RA exercises discussed earlier has learned that working groups need to be continually reminded that uncertainties classified 'medium' or 'low' (as defined in the uncertainty classification tables) must be substantiated as such by assuring that references are included in the report ('open to review')

4.2.9. General factors complicating RA of animal welfare

Following an appropriate RA approach – use of models

Dransfield and Scheffer (1991) provided basic arguments for what approach might be most suitable in developing models. In the following two paragraphs the essentials are summarized.

Statistic (empirical, descriptive, input-output, black-box, stochastic) models essentially relate the 'output' or dependent variable (y) of the studied object to the 'input' or dependent variable (x) in an empirical way, as in the typical example of simple linear regression: $y = ax + b$, by which a straight line representing the best fit is plotted through the data. When no additional knowledge is available a straight line is the best choice. However, one should remain aware of the danger of drawing nonsensical conclusions that are sometimes suggested by a linear regression approach. When theoretical knowledge on contribution phenomena is available to substantiate this one may choose to apply a multiple regression approach (i.e. a curvilinear relationship)

Deterministic (analytical, theoretical, process-orientated, interpretative) models essentially describe the mechanisms underlying a phenomenon in a mathematical function. Such functions are simplified abstractions of the real world, designed to study one special aspect only (complex hypotheses about how the system works). Such models need to be constantly subjected to careful scrutiny if the theoretical assumptions on which the function is based still apply ("garbage in, garbage out"). Hence such models can be applied more universally because the differentiated model structure allows for adaptation for all kinds of model situations. Designing computer-based programs ('expert systems') in which all available expert knowledge is compiled is a cumbersome process as it involves obtaining and classifying the relevant information from experts, many of which appear to be unable to explain how they arrived at their final conclusion.

In the RA of animal welfare, both stochastic and deterministic models can be considered. The multi-factorial character of animal welfare and the discussion within the animal welfare science community whether or not weighting factors for each of the various welfare components can be assigned in the first place, complicates the decision on what approach is most suitable. In the developing phase of welfare risk assessment the 'informed opinion' of welfare experts plays an important role as long as the theoretical knowledge is incomplete. On the other hand, the RA exercises commissioned to expert working groups in the framework of the underlying and other mandates generate an important data base (to be continuously updated to assure its validity) that can be used for developing computer-based 'expert systems'. The results of 'semantic' models based on such systems [e.g. those developed by Bracke et al. (2008) addressing specific welfare problems for which certain factors (e.g. attributes of a housing system) are analyzed] are promising, and these will certainly contribute to improving the reliability of RA models particularly in terms of hazard characterization and to assessing the suitability of various production systems

Other concerns
In the largely stochastic approach chosen by most welfare risk assessors, it was assumed i) that there is no interaction between hazards, ii) that there is linearity in the severity scores and iii) that hazards are mutually exclusive where this may not always be the case. However, it remains to be considered if such assumptions are justified.

Interaction between hazards is not unlikely to occur. For instance exposure to dust and exposure to ammonia will together increase the risk of pneumonia and associated welfare problems. Consequently, an inherent danger of comparing risk estimates calculated for individually listed hazards is that their significance may be over- or underestimated, particularly when mechanisms of interaction are less known. Also, the adverse effects may interact (e.g. fear causing stress or acute stress reducing the perception of pain). Conversely, when there is consensus about major interactions and their underlying mechanism these could be considered - e.g. by entering in RA tables major scenarios prevailing in (industry) practice - to enable reliable scoring of interactive hazards.

Often (i.e. particularly in the absence of evidence from literature suggesting otherwise) linearity of adverse effects is assumed to not unnecessarily complicate risk calculation. However, it is more than questionable if, for instance, 4 time units of severe pain (level 3) equals 6 time units of moderate pain (level 2) or 12 time units of minor pain (level 1). In this example it must also be considered that the pain experienced over time can be attenuated or aggravated dependent on applying or withholding proper pain treatment. Finally, it should be realized that when multiple adverse effects (pain, frustration, behavioral disorders etc.) result from a hazard, the durations (duration-1; see below) of the different effects may be different, in some cases possibly even longer than the exposure to the hazard (duration-2; see below). Again, provided a clear understanding of the presence-or absence of linearity is given, these can be addressed by entering specific scenarios.

Clearly defining the terminology of RA is essential to ensure transparency of the methodological approach as well as to allow repeatability of the process when this is deemed useful at a later stage. To this end including a clearly formulated glossary of terms and tables with unmistakably defined descriptions is essential.

4.2.10. Composing and correctly interpreting RA tables

A proper RA table includes a Hazard Identification (HI), Hazard Characterization (HC) and an Exposure Assessment (EA) section.

Hazard Identification
For listing factors possibly representing hazards to animal welfare it is helpful to first identify various production/management/handling options that differ substantially in the type of hazards to be considered [e.g. major husbandry-, transport- or (as in this report) lairage/stunning systems practiced for a particular species]. Each of these is to be presented in a separate RA table, by which specific categories of interest (e.g. housing, nutrition,

management, genetics etc.) are systematically analysed for relevant hazards. Obviously, it is to be assured that all its members fully appreciate the various production options and related scenarios and how these are practiced *lege artis*. Only then one can afford to begin with the listing of potential hazards.

An approach which has proven useful for not overlooking relevant factors is through cross-checking (challenging) production options with a list of 'animal needs' using 'guide words" (e.g. 'too high' or 'too low', or rather more quantitative terms such as 'more than' or 'less than' a critical value, i.e. rather similar to the HAZOP technique applied in HACCP studies on food safety (Baird Parker, 1987). This procedure leads to a comprehensive list of hazards to be further considered.

In the process of discussing the various hazards, the working group may decide it is necessary to separately address more specific scenarios that more clearly distinguish the attributes that make a factor a potential hazard (e.g. 'poor feed quality' in two scenarios thus distinguishing 'poor nutritive value' and 'presence of pathogens'). For this purpose an additional column (under the heading: hazard specification) needs to be included. Should one - for reasons of table lay-out – choose to include short and less clear terminology, it is important to add a reference to where in the report the specifications are more clearly discussed. The latter approach will inevitably result in RA tables becoming rather extended. By the same token it serves transparency and increases the ability to confront stakeholders, who might otherwise give their own, not necessarily correct interpretation of the results.

Specific scenarios should reflect conditions commonly prevailing in practice. For reasons of practicability their inclusion should be limited to the most important ones (e.g. addressing climatic conditions, breed-specifics or indeed situations where hazards interact) in the realization that the effects of other scenarios can be assessed through extrapolation or (in exceptional situations) should be considered in a specific RA.

Hazard Characterization

To assess its magnitude, both the severity and duration (-1) of the adverse welfare effect needs to be determined. The fact that overall welfare is a composite of many components complicates the scoring of severity. It is important to carefully list which which animal needs are compromised and what are the related specific welfare consequences (pain, frustration, etc.) and what is the level/degree of those.

It is possible to quantitatively measure pain in terms of strength of escape behaviour, frustration in terms of 'operant effort' or 'recovery' etc. However, such data is usually not available for practical conditions. Alternatively, one must rely on data from experimental studies or turn to distinguishing severity scores by identifying animal-based (clinical) indicators by way of classification tables. In composing such tables it is important to assure transparency, i.e. unclear descriptions that are open for anthropomorphic interpretation are avoided. Welfare components are fear, pain, frustration etc. Ideally, the different welfare components should be scored separately (i.e. more clearly delineating 'explicit' from 'some' or 'minor' pain or, alternatively where appropriate, for malaise, for stress or for behavioural disorders in unmistakable terms). For reasons of practicability such an approach has not been adopted in the RA's conducted to date, probably because this procedure would inevitably lead to an almost limitless range of combinations. Instead, severity score tables refer to 'overall welfare' related to each of the hazards as for instance the one developed in the pig RA reports.

Severity score tables should be tailor-made. For instance, using the highest severity score '1' as defined in the pig welfare approach (give that description here) would in the underlying report be useless as death is the ultimate purpose of the stunning/killing procedures under scrutiny.

A slightly more focused approach [currently (2008) followed by an RA group addressing dairy cow welfare] is to concentrate a RA on specific welfare categories, such as lameness ('leg and locomotion''), mastitis ('udder problems'), 'metabolic diseases/fertility' and 'behavioural disorders' and indicating for each hazard in these categories which welfare components are of overriding importance. This procedure at least generates an outcome indicating which of these are most compromised.

In the case the effects of multiple welfare components are involved one should indicate the ones of overriding importance by underscoring (as has been done in this report).

The **duration-1** of an adverse effect is important to estimate the impact of a hazard on the individual animal's welfare. It is expressed in appropriate time units (e.g. days, or - as in this report in minutes). Again, one should realize that different welfare components may be experienced over different periods (e.g. a short period of pain but a long period of frustration). Where one considers that such has a significant bearing on the risk outcome, there is no alternative than inserting separate scores for different welfare components.

Note: The indication '-1' in Duration-1 has been attached not to confuse this variable with the duration of a scenario to which - over the considered period (e.g. life cycle, period of lactation) - the entire animal population is exposed (Duration-2; see below).

In RA's a measure for the agreement on the solidity of the HC (a quantitative expression of the likelihood) needs to be included. The extent to which the working group members can agree generally depends on the quality of the data available and/or (in case of scarcity or absence of data) principally on the match of 'informed opinions' of experts. By requesting experts to express their degree of certainty by expressing what proportion of all exposed animals that would be affected by the adverse effect ranging from what they think would be the minimum proportion of the population (e.g. 20% of the population) and a maximum proportion (e.g. 80%) and which would be the most likely proportion (e.g. 60%), the likelihood can be modelled using a Beta-Pert distribution. Consequently values will range from 0 to 100%. Unless there is documented proof to suggest otherwise, a symmetrical distribution is assumed.

The Uncertainty of EA estimates is NOT included in the mathematical equation that ultimately yields the risk estimate, but its numerical range is rather used to determine the qualitative assessment of uncertainty [expressed as H (high uncertainty), M (medium uncertainty) or L (low uncertainty)] which co-determines the overall degree of uncertainty of the RA as indicated in a matrix (see below).

Exposure Assessment

The proportion (in %) of the entire animal target population in a specified area (e.g. Europe or parts thereof) that is exposed to a certain scenario is estimated in the exposure assessment.

To this end it must first be determined what part of the considered time period (e.g. the entire life-cycle, lactation period or - as in this report – the time from unloading to stunning/killing) the scenario applies. This variable, called duration-2, is expressed in appropriate time units (days, or even minutes).

Also, each scenario must - wherever possible - include a definition of the intensity of the hazard in quantitative terms (e.g. as in the exposure to light expressed in Lux). When this is not meaningful (e.g. animals continuously being exposed to improper management) it suffices to insert 'full exposure'.

The level of uncertainty about the EA data is assessed as described for HC, and co-determines the overall degree of uncertainty as indicated in a matrix (see below).

In general, it is difficult to access reliable data sources for purposes of EA. This applies to virtually all areas in which RA is conducted. Only in rare cases exposure data are systematically collected. The latter is for instance the case for EA data on zoonoses where a defined approach to Europe-wide (yearly) monitoring has been laid down in legislation and exposure data are documented in a standardized way (European Union, 2003). For animal welfare such a monitoring system does not yet exist and it is even unclear if and which national agencies in Europe consider it their task to develop a monitoring system. The EU action plan for Animal Welfare clearly says that the EU Commission wants to develop indicators to allow on-farm assessment and certification. The Welfare Quality EU project is currently developing the tools for that. In this context it is important to realize that even merely screening the European animal welfare situation at regular periods of multiple years would render a data base by which more reliable risk estimates can be calculated. This would serve as a justifiable basis for introducing more targeted Europe-wide legislation. Obviously, the latter presumes that some of the afore-mentioned methodological issues are solved [e.g. which welfare components to primarily consider, how to measure these, based on which animal- (or associated production factor-) based welfare indicators etc. The Welfare Quality project may suggest solutions to this issue.

For purposes of generating (more reliable) estimations on EA, it usually does not suffice to exclusively rely on the information of working group members, as these might not be fully aware of the situation in a larger area such as the EU. This particularly applies when the geographical areas to be covered is large. Consequently - especially when deemed necessary for formulating legislation - it is recommendable to rely on consulting field experts from the various sub-regions (countries) and solicit more detailed information, e.g. through 'consultants meetings'. One must ensure that the individuals delegated to such meetings are independent, preferably have access to documents substantiating their statements (or, alternatively, can base their estimations on a thorough knowledge of the local situation and the production/processing option under scrutiny). Only then unnecessary arguments with stakeholders can be prevented.

Risk Characterization
The risk is estimated as the magnitude of the hazard times the probability of the adverse effect occurring given hazard occurrence times the probability of exposure to the hazard. This is done using a Monte Carlo simulation and Pert probability distributions.

Hazards with a high magnitude (i.e. very relevant as they produce a major adverse effect in an individual animal) but a low exposure (i.e. relatively few animals in the population being subjected to these hazards) yield risk estimates that - erroneously – would seem to suggest these are less relevant and consequently would not necessarily receive the risk managers' primary attention. However, as animal welfare legislation aims at avoiding unnecessary suffering and was certainly not exclusively formulated for the population level) it is essential that such scenarios are properly dealt with in welfare management. They would seem to be best addressed by assuring that producers are aware that these 'extraordinary' circumstances DO occur (under circumstances to be specifically described) and can entirely be prevented by strict adherence to 'Good Practices'.

Usefulness of graphics for expressing RA outcomes
Graphically expressing the RA outcome (i.e. principally distinguishing risk magnitude and risk estimate in one figure) serves an important purpose, in that it allows the experts involved to identify the correctness of unexpected ('odd') outcomes that would at first sight not appear to make sense. Past experience shows that some of these are indeed the result from failure to properly fill out the tables. With few exceptions, welfare experts are less familiar with the RA methodology and without proper guidance by a risk assessor inclined to misinterpret some procedures.

4.3. The feasibility of identifying "welfare promoters" and options for benefit analysis

Animal welfare is a continuous variable on a scale from high to low. In more discrete terms welfare could be classified in certain ranges (e.g.'optimal', 'suboptimal but acceptable' to 'unacceptably bad'). Under the limitations of current production systems animal welfare will rarely reach its maximum. These limitations are not necessarily only associated with economic considerations (or ignorance of the profitability of good welfare), but also with animal- and public health concerns and environmental and energy conservation issues. In addition, in view of the multi-component character of animal welfare, optimally addressing one of those components may compromise another (compare free range systems allowing a natural habitat and promoting natural behaviour but increasing the risk of animals contracting parasitic diseases). In consequence, one must confront the fact that in animal production practice (and in nature for that matter) welfare may rarely reach its maximum.

The desirability to improve animal welfare beyond simply eliminating major welfare risks has inspired discussions on whether or not (parallel to avoiding adverse effects of identified hazards) 'promoters' of animal welfare should be identified as well, and in this framework the term 'risk-benefit analysis' (RBA) is used (e.g., EFSA, 2008). This concept is known from food toxicology, where it is for instance applied for assessing the risks and benefits of including nutrient components at critical levels. A classic example is nitrite added to curing salt, which is known to effectively prevent the growth of *Clostridium* spp. in cured meats, but at levels in salt of higher than ca. 0.5% would represent a risk for the formation of the carcinogenic nitrosamine.

As the methodology of RBA is in its early development stage, guidelines for its proper application even for the food toxicology area are not available (EFSA, 2006).

The most important question in this context is how - else than through determining (by relying on animal-based welfare indicators) that adverse welfare effects are absent - one can decide that a certain factor is a 'welfare promoter' without anthropomorphic interpretation. Conversely, should benefits be interpreted in terms of 'absence of risks' the methodology described in this report serves the purpose of benefit analysis, in that neglecting those factors that decidedly promote animal welfare (and consequently are to be considered 'Good Practices') are defined as hazards.

Note: Comparing different production (husbandry) systems to assess their potential to promote animal welfare (in which the presence-or-.absence of various hazards occurring in one or the other system is carefully considered) is sometimes also referred to as 'benefit analysis'. However, the use of this term in this context is confusing.

5. Identification of animal welfare hazards during stunning and killing

5.1. Electrical stunning

Electrical methods are by far the most commonly used stunning and slaughter applications in meat animals (Gregory and Wotton, 1985. Anil et al., 1997; Lambooij et al., 1997) Rendering animals unconscious by producing brain dysfunction with or without subsequent killing by cardiac arrest is the aim so that exsanguination is carried out (Cook et al., 1996, 1999; Anil, 1991.; Anil and McKinstry, 1991, 1992; Raj et al., 2004a, 2004b).

5.1.1. Electro-anaesthesia (head only stunning)

A specially applied method of electro-anaesthesia is widely used for the stunning of slaughter animals. Electrical stunning is based on the induction of a general epileptiform insult ('grand mal' or seizure-like state) by the flow of an electrical current through the head and brain. Provided that sufficient current is administered through the head of an animal a general epileptiform insult (spreading across parts of the brain stimulating many cells) will occur. The epileptic process is characterised by rapid and extreme depolarisation of the membrane potential and development of a synchronised electrical response. This can be measured and observed on the recorded electroencephalogram (EEG) as such an insult produces relatively small waves increasing in amplitude in the tonic phase (rigid), and decreasing in frequency in the clonic phase (high motor activity in muscles) resulting ultimately in a period of strong depression of electrical activity in pigs, sheep and calves (Anil, 1991, Anil and McKinstry, 1993, Anil et al., 1998; Lambooij 1982a)

However, the general epileptiform insult seen on the EEG of some birds and fishes is characterised by a tonic/clonic phase and a quiescent phase. The duration of the insults differs between species. Since human subjects are known to lose consciousness during the three phases of a general epileptiform insult, by analogy, other mammals are also assumed to be unconscious and insensible. On basis of similarities in basic structure of neurones and neuronal biochemistry, it can be argued that this analogy is also valid for fish.

During epilepsy the brain remains in a highly stimulated state being unable to respond to stimuli. Another contributing factor is the release of several neurotransmitters in the brain during such an insult. Several studies, in which neurotransmitters have been measured, coupled with pharmacological experiments, have suggested that the general epileptiform insult induced by electrical stunning is dependent on the release of vasopressin, oxytocin, glutamate, aspartate and GABA (gamma amino-4-butyric acid). The first phase induced by the stun produces the tonic phase through the release of the excitatory neurotransmitter glutamate. This is followed by the release of GABA that assists in the recovery if the animal is not killed.

A minimum current threshold level, which is a function of the electrical impedance of the head or the body, is necessary for the effectiveness of such an insult. Brain tissue impedance has been used as a measure of changes in the extracellular volume (ECV) and it has been found to be a valid indicator in ischaemia-induced brain damage in experiments with broiler chickens. Animals that were bled only showed a decrease in base extracellular volume after four minutes post mortem, while electrical head-to-body stunning, inducing cardiac fibrillation, caused an immediate and gradual increase in brain impedance. This suggests that the latter method provides an immediate effect on the brain. On the other hand, head-only stunning followed by exsanguination produced a dual response pattern. Some animals showed a response similar to animals that were bled only, and some animals were similar to those receiving head-to-body stunning. However, various physiological processes may contribute to this effect. Therefore, it cannot be concluded from this study that head-only electrical stunning provides an adequate stun in all cases.(Savenije et al., 2002).

Epilepsy affects the behaviour of the animal. Immediately after induction of electrical stunning either tonic or clonic muscle activities are observed. In mammals the extensor muscles are stronger than the flexors causing the extension during electrical stunning. In studies with eels that were able to move freely, these animals initially showed limited tonic/clonic cramps combined with much backward swimming, later followed by heavy clonic contractions combined with uncoordinated movements such as jumping out of the water (Lambooij et al. 2002). The flexors and extensors in eels are considered to be equal in strength; this may explain the observation of limited tonic and clonic cramps combined with much backward swimming. Other fishes just showed a tonic/clonic phase followed by exhaustion (Kestin, 2002)

The most common electrical stunning method for animals uses a frequency of 50 Hz alternating current (AC.) with sinusoidal waveform. The frequency can be as high as 1800 Hz

(Anil and McKinstry, 1992; Lambooij et al., 1997) and the waveform can be square or rectangular. High frequency electrical stunning can induce epilepsy in the brain. However, the durations are shorter than those with 50 Hz.

5.1.2. Electrocution (head-to-back stunning or cardiac arrest)

In "head to body" stunning, the animal may die due to a heart failure, which is recordable on an ECG (electro-cardiogram). As in the brain, neuronal interactions in the heart function in an integrated and orderly fashion. Disorder is initiated by direct stimulation by electrical currents and the heart will fibrillate or stop. The heart failure results in loss of blood pressure and lack of oxygen supply to the brain (cerebral ischaemia) and affects the characteristics of general epileptiform insult (Anil et al., 1991; Cook et al., 1996; Warrington, 1974, Wotton et al., 1992)

Fishes are effectively stunned in fresh and salt water using plate electrodes. It was observed that an effective procedure for electrical stunning and killing may consist of an effective initial stun followed by a combination of low current stun and partial de-oxygenation by flushing the water with nitrogen to kill the eels, or a low current stun or immersion in ice or decapitation or bleeding in other fish species (Lambooij et al., 2002; De Vis et al., 2003).

5.1.3. Final consideration

The insight into the stunning process that has come from neuro-physiological studies is of important significance. Assessment of more parameters than general epileptiform insult and analgesia may support the humaneness of the stunning and killing system. EEG and neurotransmitter release measurements have been used to assess the effects of electrical head-only stun duration on welfare (Cook,1999,1992,1995,1996;Lambooij, 2004). An understanding of the physiological mechanisms underlying the effects of electrical stunning may help to clarify the effect of several conditions on the effectiveness of stunning and killing. Stress before killing increases some neurotransmitters, which may affect the post stun reflexes and unconsciousness (Bodnar,1984; Cook, 1999; Tume and Shaw, 1992). Combining head-only stunning with exsanguination has a synergistic affect on the release of glutamate and aspartate, which increases the duration of unconsciousness (Cook, 1996). Sticking following a stun should be carried out as promptly as possible when using head-only stunning as it takes time depending on the species before brain responsiveness is lost following sticking (Anil, 1999; Hoenderken, 1978).). It is widely recognised that inducing a cardiac arrest at stunning has distinct welfare advantages: 1) it results in a rapid loss of brain function, 2) it ensures that the animal will not regain consciousness and 3) it does not depend on the operator performing an accurate stick (Anil, 1991; Gregory, 1994; Wotton et al., 1992).

A major point that deserves particular attention is whether stunning actually renders the animal unconscious and insensible. Although this is usually believed to be the case, recent experimental findings cast some doubts upon this assumption (Lambooij, 2004).

5.1.4. *Body effects*

Various stunning methods and electrical parameters have been reported to have a different effect on post-mortem rigor development (Devine et al., 1984; Gregory, 1984; Hillebrand et al., 1996; Bilgili, 1999, 1992; Roth et al., 2002, 2003). The post mortem metabolism is largely a consequence of indirect stimulation through nervous pathways.

Broken vertebrae can occur when stunned with head-to-back electrode positioning if the voltage and the current is too high (Wotton et al., 1992; Troeger and Woltersdorf 1990). Sinusoidal alternating currents of 50 Hz have a large stimulatory effect on skeletal muscles which can be reduced by increasing the current frequency to an extent that prevents the occurrence of broken backs(Gregory et al., 1995) The prevalence of broken vertebrae and pelvises could be reduced to zero by increasing the frequency from 50 to 1500 Hz. The drawback of this approach is that the effect on fibrillating the heart is also reduced Anil and McKinstry, 1991;(Wotton et al., 1992)

Haemorrhages can be induced by stunning and killing, however, the underlying mechanism is considered to be multi-factorial (Kranen et al., 2000a; Troeger and Woltersdorf., 1990. Gregory et al., 1995). Investigations revealed that the morphology of haemorrhages was dependent on the tissue in which they occurred. In the pectoral muscles extravasating blood was found to follow the direction of the muscle fibres. In fat tissue, the majority of haemorrhages had a petechial appearance. More diffuse haemorrhages were found in loose connective tissue ((Kranen et, 2000b Hillebrand et al., 1996). The histological study of haemorrhages in different types of muscles showed that the morphological appearance of the blood extravasation is determined by the structure of the tissue as well as by the amount of blood leaving the circulation. Some haemorrhages were associated with hyper contracted and disrupted muscle fibres, indicating that they were caused by severe muscular strain. Many haemorrhages were found near venules or veins, and were packed with erythrocytes, surrounded by intact adipocytes and connective tissue. Rupture was observed only in venous structures, such as post-capillary venules and small veins, not in arterial vessels. This strongly indicates that a local rise in venous blood pressure can cause rupture of venules and small veins (Kranen et al., 2002a)

5.1.5. *Application*

- Head-only electrical stunning can be used in general for all animals, however, this method should be followed by exsanguinations for mammals and birds or immersion in ice (water) for fishes.
- Electrocution has proven to often be ineffective in small animals with a relatively high heart rate or small heart weight such as rats, mice and fishes, possoms: recovery after cardiac fibrillation, can kick start heart spontaneously) anecdotal evidence.
- Electrocution has not been sufficiently studied in many cold-blooded animals.

Application for game

It seems that the use of electrical head-only stunning, although effective when the head of the animal is properly restrained (Taylor, 1986), has found limited use. It is far more common to kill the animals either via captive bolt or with free bullets (see below) released from rifles or pistols at distances from <1 m to 40 m and more.

5.2. Mechanical stunning

Mechanical methods, can be divided into penetrating and non-penetrating applications and principally operate by causing concussion. Mechanical methods that principally refer to captive bolt guns also include use of free bullet and rifles. In addition to conventional stunning cattle, guns are routinely used for emergency killing casualties, on-farm culling and for disease control. Captive bolt guns are usually required to be present as back up in case of failure of the main stunning equipment at abattoirs.

5.2.1. Penetrating methods

Missiles used for stunning and killing of animals include free bullet, a bolt, and water jet and air pressure. Immediately after stunning animals express a tonic spasm for approximately 10 s prior to relaxation, however, excessive convulsions often follow (Lambooij and Spanjaard, 1981). Immediately after shooting major changes (delta and theta waves tending to an iso-electric line) are seen on the EEG (electro encephalogram)and it is assumed that the animal is unconscious by analogy due to similar EEG changes described in man (Lambooij, 1982b; Lopez da Silva, 1983; Daly, 2003, 1987; Daly and Whittington,1986, Daly et al., 1986, 1987, 1989).

In general, penetration of a missile into the brain can cause injury in the following three ways, depending on it 1986s velocity and shape: by laceration and crushing (<100 m/s), by shock waves (about 100 to 300 m/s) (Hopkinson and Marshal, 1967) and by temporary cavitation effect (>300 m/s). In fact, using the formula of $e = m \times v^2$, where e=energy, m=mass, and v=velocity, it has been shown that the delivered energy required for effective stunning is determined by the velocity of the missile (Crockard et al., 1987; Daly et al., 1987; Lambooij et al., 2007). However, secondary tissue damage by penetration also prevents any chance of recovery.

Captive bolt
The aim of captive bolt stunning methods is to cause concussion by transmitting the energy from the missile (bolt) into the cranium and brain. Captive bolt stunning is based on energy transfer via an agent (a cylindrical steel bolt) which retains mass and shape, and operates at low speed (<100 m/s). The velocity of a bolt of a captive bolt can be about 100 m/s in the air. This relative low velocity and shape of the bolt should crush the cortex and deeper parts of the brain and cause haemorrhages either by the bolt itself or by forward shock waves. Concussion and shearing forces also result in haemorrhages and lacerations. Captive bolt stunning is widely used for red meat farm animals. Cartridges filled with gunpowder, compressed air or springs under tension are used to drive bolts (missiles) against and through the skull of farm animals. The ideal shooting position is frontally on the head.

Captive bolt stunning is a relatively safe technique, but requires that deer is adequately restrained (DEFRA, undated). Positions for placing the captive bolt pistol are similar to those recommended for cattle, see Fig. 1.

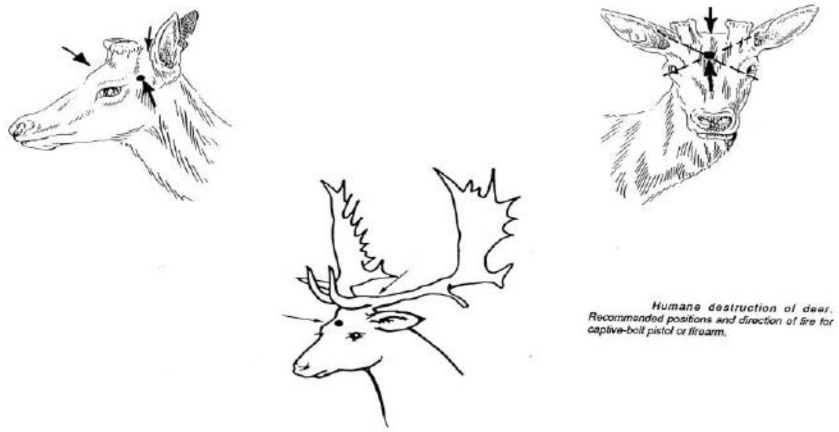

Figure 5.1. Positions for placing the captive bolt pistol in deer (from Australian Best Practice Programme for Deer Farming, June 2001).

Free bullet

Killing by free bullets is applied on free (hunted) and farmed game, and occasionally in cases of emergency slaughter or euthanasia. Guidelines for effective killing of farmed deer by free bullets have been issued in many countries (e.g. UK: DEFRA, undated, British Deer Farmers Association, 2004; Germany: Bavarian Research Center for Agriculture, undated). They basically address:

- appropriate bullet diameter and energy
- placement of the shot (frontal head, high neck or thorax)
- precautions that bystanders are not injured and that remaining animals are not injured or unduly disturbed

Free bullets have a lower mass than bolts of captive bolt stunners, and travel with higher velocity (typically >300 m/s for rifles). To improve energy transfer, bullets are constructed to fragment and/or deform when hitting the target. The energy of the bullet and the flatness of the bullet trajectory is mainly determined by its velocity (up to 1000 m/s), while the bullet mass (ca. 7-15g for wild deer) has some relevance for the stability of the trajectory and for the mode of the energy transfer within the target tissues.

Detailed requirements have been formulated by DEFRA (Table 5.1). The Bavarian State Research Center for Agriculture recommends bullets of min. 6.5 mm diameter with initial energy of 2000J (or 5.6mm with 300J for fallow deer <25 m; head shots).

Table 5.1. DEFRA recommendations on bullet diameter, shooting distance and target organ.

Location (target organ) / distance	<1 m	>1-20 m	20-40 m	>40 m
Head (brain)[a]	yes, 22" long rifle sufficient	yes, min. 0.243" bullet (6.2 mm) diameter		nr[b]
High neck (spinal cord)	ns[c]	yes, min. 0.243" bullet (6.2 mm) diameter	yes, min. 0.243" bullet (6.2 mm) diameter	only by proven marksmen
Thorax (heart-lung)	ns	yes, min. 0.243" bullet (6.2 mm) diameter	yes, min. 0.243" bullet (6.2 mm) diameter	yes, min. 0.243" bullet (6.2 mm) diameter

[a] Through brain; frontal or poll position, or halfway between eye and ear.
[b] nr, not recommended.
[c] ns, not explicitly specified, but possible for bullet diameter min. 0.243".

For killing of wild deer, it is recommended that the animal is standing broadside and the target areas are the head (neurocranium) / neck or the cranial part of the thorax.

Shots in the head will do no damage to the carcass, and are, thus preferred by professional hunters (Urquhart and McKendrick, 2006), both for wild as well as farmed game. While advantageous for "meat-getters", and effecting immediate death of the animal, the head should be considered an ideal target only under optimum conditions (distance, weather). Its relatively small size, the fact that deer as well as other wild ruminants tend to move the head suddenly for various reasons (grazing, vigilance etc.), and finally, that shooting distances for deer may be up to 200m, make it a relatively small and motile target.

Also, some wild ruminant species carry antlers which are highly valued trophies in some countries and should not be destroyed during killing of the animal. The other target area (thorax) is an area delineated by the caudal contour of the shoulder blade, the humerus and a line drawn from the elbow to the caudodorsal end of the shoulder blade. A hit in this area will cause destruction to the basis of the heart, and also rupture the large blood vessels. Also, lungs will be affected (Winkelmayer, Malleczek, Paulsen, and Vodnansky, 2005). Depending on the exact point of impact, secondary lesions can be affected by bone fragments etc. This target area also considers some possible deviations in the point of impact due to bad weather conditions (wind), sudden movement of the animal etc. Implications of killing method on the microbiological quality of game meat have been recently reviewed (Gill, 2007).

DEFRA (undated) recommends the following precautions to prevent injuries of people or animals: "A safe backstop for the bullet is needed and care must be taken in shooting one deer not to injure others. Shooting from an elevated position such as a high seat or trailer is often helpful in these respects. Sensible precautions for public safety include shooting in the early morning when few people are around; walking the perimeter fence of small farms or paddocks on large farms to ensure all is clear; shooting away from roads, houses and gardens." Also, DEFRA recommends that "shooting should be undertaken, preferably by the regular stockmen, when deer are quiet, as will occur at a selected regular feeding site when they are being hand fed. Under such circumstances it may be possible to shoot 10 or more deer from a large group before the remainder become unduly disturbed. Factors to take into account in assessing the effect shooting will have on the rest of the herd and deciding the number to shoot include the size of the original group, stocking density and the amount of cover. Care should be taken not to leave too few since small numbers become unsettled and try to escape. There is also a risk of panic if too small a paddock is used." Handling and use of firearms is subject to national legislation, which in most cases requires some familiarity in use of the guns and also should secure sufficient marksmanship.

Water jet

High water jets developed for cutting and drilling in solid materials are available for use as stunners. Experiments to explore the suitability of water jets for stunning and killing purposes were conducted under laboratory conditions using post mortem materials e.g.(pig heads) and also on live slaughter pigs (Schatzmann et al., 1990). Immediate unconsciousness as determined by EEG, was initiated by a rapid penetration of the skin and skull. In these studies destruction of the brain occurred within 0.2 to 0.4 s. The water jet, if employed, should be aimed frontally on the head and injected into the cranial cavity at the intersection of the imaginary lines from the ear to the opposite eye.

A potential problem with water jets could be the excessive convulsions, that can appear after the use of this stunning method (Lambooij and Schatzmann, 1994).This is because - whenever an animal is decerebrated - convulsions (i.e. muscle contractions) of the carcass, caused by stimuli evoked in the medulla oblongata, mainly occur in the hind limbs.

Air jet

Development of captive bolt stunning has been negated in most species due to lack of means to prevent post-stun convulsions. Recently, a captive needle stunning device for broilers has been developed, by which air pressure is injected into the brains and partly directed towards the spinal cord (Hillebrand et al., 1996). The latter extension is thought to prevent the convulsions. In broilers the air pressure stunning reduced post-stun convulsions to less than 13 % of the level of convulsions (Hillebrand et al., 1996). Additionally, a captive bolt stunning method for broilers has been modified so that air pressure is used to block post stun convulsions (Hillebrand et al., 1996). In order to improve the method of practical application a commercial air tacker was modified (Lambooij et al., 1999). The plunger of the original design was replaced by two needles, which penetrate the skin and skull at an angle of 15o in caudal direction. Both needles were provided with small holes allowing air through in different directions. The stunning position was at the intersection of two imaginary lines drawn from the ear on one side to the inner corner of the eye on the other side. A trigger starts the injection of compressed atmospheric air when the needles penetrate the skull, and the duration of air injection was electronically controlled. The duration of injection as well as the air pressure was adjusted to a shooting pressure of 8 bars and an air injection of 3 bars for 1.5 s. It is hypothesised that the compressed atmospheric air administered through the needle in the captive pistol, placed more anteriorly on the animals' head, damages the higher brain regions to provide unconsciousness, while the other needle damages the upper spinal cord to prevent post stun convulsions (Lambooij et al., 1999).

The captive needle pistol was adapted to guinea pigs, eels and cat fish regarding the length and shape of the needle (Lambooij et al., 2002). Only one cone shaped needle of 16 mm was used, which pressed the air in 3 directions radial 120o, where one direction was caudally towards the spinal cord. For correct positioning on the head an adapter was placed at the barrel of the pistol.

5.2.2. *Non-penetrative methods*

Cerebral concussion is generally agreed to be a traumatically induced derangement of the nervous system, resulting in an instantaneous diminution or loss of consciousness without gross anatomical changes in the brain (Ommaya et al., 1964, 1971; Ommaya and Gennarelli, 1974). Irrespective of the type of force which produces the traumatic depolarisation of the cell membrane there is now evidence that powerful pressure waves are provoked within the cranial cavity by a blow on the head and that the frequency and force of the waves vary in different parts of the brain (Ommaya et al., 1971). It has been suggested that it is not the pressure as such developed by these waves that is the important factor but the rapid oscillations in this pressure (Lambooij et al., 1981).
It should be noted that many investigators (EFSA) consider blood flow impairment as being primarily responsible for the electrical changes in the brain, although the immediate changes in the brain cannot be explained by this theory.

5.2.3. *Neck dislocation and neck sticking*

It is well known that in nature some predators use the method of cervical dislocation to immobilise and kill their victims. In this method the head is turned in opposite direction to the body while stretching the neck and concomitantly turning and stretching, blood vessel are crushed and bleeding occurs.

For neck dislocation in practice, the spinal cord is destroyed by thrusting a knife into the intervertebral space between the head and the 1st or 2nd vertebra. After dislocation or thrusting a knife a tonic cramp occurs resulting in paralysis after 5 to 10 s. (Gregory and Wotton, 1990c). Removal or inhibition of the contact between brain and spinal cord causes apnoea and loss of (pain) sensory perception from the body and spinal shock, with the exception of the face innervated by the 5th cranial nerve (Eichbaum, 1975).

5.2.4. *Decapitation and bleeding*

In this method the head is separated from the body of the animal using a knife. An alternative method for animals with a long neck involves stretching by hand. And as a result bleeding occurs. A guillotine has also been developed for use in rats (Eichbaum, 1975). By this method direct bleeding occurs by severing the neck including the main blood vessels.

5.2.5. Final consideration

Most studies investigating the mechanism of concussion (e.g. Ommaya et al., 1964) were performed with laboratory animals (i.e. rats, cats, monkeys) (Shah et al., 1982; West et al., 1981). It is evident from these investigations that concussion does not always cause loss of consciousness. In man retrograde amnesia after the blow often occurs making interpretation of the effects less certain (Ommaya and Gennarelli, 1974). It is also known that successive severe blows result in prolonged loss of reflex activity and almost complete abolishment of all frequencies in the EEG and appearance of an iso-electric line.

In regard to fish, mechanical stunning methods, such as percussive, spiking and decapitation are used. There is potential for both percussive stunning and spiking methods to be mechanised. However, it is essential that the blow is delivered correctly to ensure that consciousness is lost immediately. Mechanical methods are recommended for use under practical conditions, however, it is concluded from observations of the head of eels, that signs of life were shown for a considerable time after decapitation (Schelvis-Smit, 2002). Fish are known to have a robust CNS activity that can persist for a long time after production of anoxia (Van de Vis et al., 2003a; Kestin, 2002).

It is generally known that the removal of inhibitory influences from higher centres of the brain (e.g. damage by captive bolt) , results in convulsive activity and enhanced spinal reflexes lasting until eventually the spinal cord becomes anoxic (Eichbaum et al., 1975). However, following decapitation convulsions only occur if the cut is made cranial to the fifth thoracic vertebra, while cuts caudal to this location result in paralysed animals.

5.2.6. Application

- When adapted to the species a captive bolt can be used generally.
- Because of operator safety implications free bullet is not recommended.
- Percussion stunning can be used in several warm and cold blooded animals, however, there may be some doubts about consistent and reproducible effective stunning and killing.
- Neck dislocation and sticking are not recommended, because the animal is not unconscious immediately and may suffer for some time.
- There is ongoing discussion about the use of decapitation and bleeding, However, it is not recommended only for a special reason not compromising the result of the experiment. Electrical stunning prior to decapitation may offer an alternative.

6. Stunning methods and the public health implications

Although, the focus of this review is on animal welfare, in some instances, public health measures and concerns, especially as a result of the BSE threat, have inevitable welfare consequences too. To this end, a detailed EFSA opinion on stunning methods and public health implications has been prepared (EFSA, 2004).

Potential public health concerns from TSE infected animals have been considered and reviewed (Anil and Austin, 2001). In cattle stunned with a penetrating captive bolt (PCB) method a frequency of 4%, CNS embolism in jugular blood of with a 95% has been reported (Coore et al., 2004, 2005). In sheep, higher frequencies (23% and 14% respectively for cartridge activated and pneumatically activated guns) of CNS embolism in jugular blood have been reported (Anil and Harbour 2001; Coore et al., 2004). As the heart continues pumping for several minutes between the stunning and the end of exsanguinations ,some of the embolic CNS material dislodged by the penetrating captive bolt gun might enter venous blood vessels draining the head and consequently be disseminated to other organs/tissues. This can happen not only with use of a penetrating gun that injects air into the brain (Schmidt et al., 1999) but also when stunning is performed without air injection (Anil et al., 2002; Coore et al., 2004, 2005) In NPCB stunned cattle, CNS material was detected in jugular blood of 2% animals (Coore et al., 2004, 2005).

In addition to haematogenous contamination of edible tissues with CNS material, other public health concerns may also be associated with PCB methods. For example, cross- or airborne contamination of the stunning gun operator, the environment such as the stun-box and/or the animals consecutively stunned with the same gun could occur, based on studies using experimental contamination with marker bacteria (Prendergast et al., 2004).

6.1. Physical methods

6.1.1. Heating up

Since the end of the 19thy century high frequency electric currents have been used to heat tissues. Long wave diathermy, using frequencies in the order 1 MHz required the use of electrodes which were in direct contact with the skin and consequently the risk of burning was high. Later frequencies known as short wave diathermy were introduced with the advantage that it was not necessary for the electrodes and the skin to be in contact being air between it (Lambooij et al 1990).

In a reported procedure (Guy and Chou, 1982) heads of rats were irradiated with micro waves of 2450 MHz for 1 s the temperature in the brain increased up to 75-90oC within the next 1 s. Consequently it was shown the brain enzymes are inactivated very rapidly, that they can be used in neuro-chemical investigations. It was observed that an increase of about 10oC in the brain resulted in a clinical state of unconsciousness using 2450 MHz (6kW) for 1,5 to 2 sec. A change of 6.4oC at a depth of 3 mm could cause a stunning effect using 915 MHz. After seizure the rats lay in an unconscious state for a period of 4 to 5 min.

6.1.2. Cooling down

The current pre-slaughter process used for fish consists of live chilling to immobilise them prior to evisceration. Assessment of live chilling revealed that this method is stressful as vigorous activity of the animals and irregular heart rates were observed (Lambooij et al 2002.

Responses to pain stimuli disappeared at a body temperature of approximately 8 to 10^{o}C, that occurred after 10 to 15 min, suggesting that consciousness is lost by this time.

A patented alternative method of stunning and killing eels (Lambooij et al 2002; Rorvik et al., 2001) (involves cooling them down gradually until death. According to the patent description the eels should ideally remain at least for 10 min in a medium with a temperature below -20 ^{o}C. A saturated brine solution at -15 ^{o}C may also be used.
In addition, the eels should be stunned prior to killing by cooling down the body temperature to between 0 and 5 ^{o}C.

Placing eels in brine at -18 ^{o}C is an effective method to kill the eels. However, it cannot be recommended to place conscious eels in cold brine water, because it takes more than 27 s before unconsciousness may be induced.

6.1.3. Fragmentation

Instantaneous fragmentation in a high-speed grinder may kill a small animal within a second. Grinders with rotating blades with a speed of 2800 turns per min and a power of 4 KW may be useful for small birds (Kettlewell, 1986). For a correct result the grinder may not be overloaded. A capacity can not be recommended. However, it is argued that for welfare reasons may be animals should be unconscious first (e.g. chick placed in CO_2 atmosphere first).

6.1.4. Final consideration

During live chilling, theta and delta waves appeared on the EEG traces and responses to pain stimuli disappeared after 10 to 15 minutes (Lambooij et al 2002; Rorvik et al., 2001). Occurrence of theta and delta waves and no response to pain stimuli, both on the EEG and in behaviour, supports the assumption that the fish were unconscious and insensible as gauged by analogy with similar EEG changes in man and laboratory animals.

In fish, stressors activate the hypothalamo-pituitary-interrenal-system and the subsequent increased release of proopiomelanocortin (POMC)-derived peptides from the pituitary gland induces cortisol release from the corticosteron-producing cells of the adrenal cortex (Rose 2002). For example, exposure of carp (*Cyprinus carpio*) to a rapid drop in temperature of 9 ºC resulted in a time-dependent cortisol response and induced a differential expression of both the POMC and mRNAs (Arends et al., 1998). Plasma cortisol levels increased up to 6 times the control level 20 min after the start of the experiment, and remained high until the end of the temperature shock. Incrased plasma cortisol levels were also observed for Atlantic salmon (*Salmon salar*) after live chilling compared to percussive stunning (Robb et al., 2000a, 2000b).

Hypothermia is not considered acceptable for euthanasia of fish, because it prolongs the period of consciousness and does not reduce the ability to feel pain (Robb et al., 2000, Kestin, 2002).

In regard to birds it is difficult to establish the appropriate capacity of how many birds may be handled without physical overloading of the equipment and reduced efficacy. The equipment is just examined on day-old chicks and not other small lab animals.

6.1.5. Application

- Diathermy of the brain is developed for rats and recommended for mice if they are trained to cope with the restraining method.
- Cooling in ice water or freezing in brine is not recommended for fishes (and other animals). Cooling can be used to kill animals after an electrical or mechanical stunning method.
- High speed fragmentation can be recommended for day-old chicks and embryonated eggs.

6.1.6. Magnetic stimulation

All stunning methods have disadvantages relating to quality, public health as well as possible misstuns. There is a need for research to develop alternative, ideally non-invasive, stunning methods (Knight and Anil, 2001). A non-invasive method that does not result in tissue damage before death could also be acceptable by Jewish and Muslim communities. In practice, an intense magnetic field is generated by passing a large current through a copper coil. The coil is positioned close to the head so that the brain lies within this magnetic field. Transcranial magnetic stimulation (TMS) has been used in humans for years. The technique also reliably initiates seizures in humans as an alternative to ECT for the treatment of depression (LISANBY 2002). Bristol research has provided evidence for insensibility during the TMS application (ANIL 2000).

Using similar technology, studies aimed at producing seizure activity and prolonged insensibility without a painful induction are being conducted using new equipment and special coils in animals (Anil et al , unpublished). If fully developed, magnetic stimulation, a potential technique for stunning animals, can be used in future.

6.2. Gasses

Because conventional electrical stunning methods can have adverse effects on carcass and meat quality gas stunning methods have been introduced and used in the last 3 decades. Carbon dioxide, the principle agent, and inert gases such as argon and nitrogen can be used and pigs and poultry are the chosen species. Carbon dioxide is also used for depopulation and disease eradication in poultry houses.

Gasses used for euthanasia can be divided into narcotic and anoxic gasses. Narcotic gasses include for example ether, chloroform, halothane and methoxy-flurane. There is a wide range of anoxic gasses available such as carbon monoxide (CO), carbon dioxide (CO_2), HCN, di-nitrogenoxide or laughing gas (N_2O), nitrogen (N_2) and argon (Ar). The most popularly used gases are CO and CO_2 or a combination of both.

Narcotic gasses cause a depression of the Central Neural System with induction of unconsciousness and muscle flaccidity (Eisle et al., 1967). An overdose leads to paralysis of the breathing muscles and the animal is killed by apnoea. During induction by a narcotic gas excitation occurs. The severity of this excitation depends on the gas used (Abraini et al., 1988).

Presence of anoxic gasses reduces the flow of oxygen (O_2) to the tissues in one way or another. HCN prevents the flow of O_2 to the tissues and causes an extreme excitation phase (Kennedy et al., 1992). CO has a stronger affinity for haemoglobin than O_2, hence reduces the O_2 concentration in the blood. The CO also causes a vascular dysfunction which in turn leads to haemorrhages by ruptures and diapedesis (Lambooij et, 1985). Other gasses, such as N_2, Ar or CO_2 work by replacing O_2 from the air to be inhaled and CO_2 in concentrations higher than 12% depresses the central nervous system directly (Aisle et al., 1967)). It is well recognised that CO_2 is an anaesthetic gas which produces rapid unconsciousness when inhaled at high concentrations. However, signs of asphyxia and behavioural excitation were observed due to occurrence of both hypercapnia and hypoxia (Ernsting, 1963).Moreover, CO_2 is an acidic gas and has been found to be painful, causing unpleasant sensations on the nasal mucosa, lips and forehead in human subjects, when gas puffed stimuli were administered in concentrations over 65% (Gregory et al., 1990). The right hemisphere of the human SII cortex is dominantly involved in this response, which may suggest emotional / motivational aspects of trigeminal pain, and is in agreement with the role of the trigeminal pathways as a general warning system Erlichman and Leiter, 1997). It has been shown that broilers can detect CO_2 in air at concentrations greater than 10% (Raj et al., 2006, Sandiland et al., 2006). Increased head shaking and the elicitation of withdrawal from feeding at 55% CO_2 and above suggest that mixtures of CO_2 in air at above concentration may have an aversive effect. In rats a low concentration of CO_2 and addition of O_2 and use of humidified gases could ameliorate these negative effects. In the latter case almost no signs of asphyxia and excitation were observed. The main action of CO_2 is not its suffocating activity, but its anaesthetic activity. A problem with O_2 – replacing gasses is their lower efficacy in younger animals (Lambooij and Spaniard, 1980). However, Ar can be easily administered in gas stunning, because it is heavier than air (as is CO_2), tasteless and odourless. Another option is a low concentration of CO_2 in Ar. Research has shown that both last mentioned gas mixtures caused a rapid loss of brain function in chickens, turkeys and pigs for stunning purposes before slaughter (Raj and Gregory, 1991a,b,c;1995Raj et al., 1997a,b;). However, pigs have been shown to aversive to high concentrations of CO_2 (Raj, 1999).

6.2.1. Final consideration

In general, exposure of animals to gas mixtures and inhalation anaesthetics, unlike some other methods of euthanasia, does not produce immediate loss of consciousness in animals. Therefore, it is important to focus on further research for gas mixtures that are non-aversive and do not induce distress or pain prior to loss of consciousness. Gaseous methods also have the advantage that animals do not have to be restrained in any way which is good from both scientific and animal welfare viewpoints.

Some species of animals are tolerant to hypercapnia or hypoxia / anoxia. Diving or aquatic species, amphibians, burrowing animals and reptiles survive these conditions by either compensatory cardiovascular mechanisms, holding their breath or due to having very slow rate of breathing,

The results of experiments on several species of farm animals (chickens, turkeys, pigs and mink) (Raj, 1996; Raj and Gregory, 1995; 1996; Cooper, Mason and Raj, 1998) have shown that they perceive carbon dioxide as extremely aversive. This aversion to CO_2 has been reported to be more overwhelming than motivation to feed (in CO_2 atmosphere) after overnight fasting in pigs and poultry. It is very likely that burrowing animals, including rabbits, would find this gas even more aversive (Hayward and Lisson, 1978).

6.2.2. Application

Carbon dioxide is denser than air (relative density 1.6) and therefore can be easily contained in a chamber. Air breathing (terrestrial and aquatic) animals are exposed to atmospheres in a chamber of CO_2 at varying concentrations. Restraint, other than inability to escape from euthanasia apparatus or cage, is therefore minimal. Concentrations may be rising from 0 to 100% or they may be exposed to a lethal concentration from the start i.e. (e.g. depending on the species 40%), or there may be staged rises in concentration (e.g. from 40 to 60 to 90%).
Aquatic species: some species of farmed fish are killed by immersion in water saturated in CO_2 (for details, refer to EFSA, 2004), but there is little specific information on the common methods used in laboratories.

In regard to farmed poultry, there may be a need to cull birds in houses during disease outbreaks. Gassing has advantages over mechanical and electrical methods or overdoses of anaesthetics because large numbers can be killed simultaneously with little or no handling of the birds. However, gaseous killing methods may have negative welfare implications for the birds. These could include aversiveness to various gases, experience of respiratory distress and/or convulsions, delayed loss of consciousness before death (Raj, 1996; Raj and Gregory,1994;Raj et al., 2006). In addition, the gases used may present health and safety risks human operators, and be difficult to supply and deliver.

Killing of poultry in houses with carbon dioxide has been investigated widely in Europe (e.g. Gerritsen et al., 2006) and in the UK (Raj, Sandilands and Sparks, 2006).However, carbon dioxide can only be delivered into reasonably sealed poultry houses.

The use of fire fighting foam has been tested in the USA and approved for killing poultry during disease outbreaks (visit, www.avi-foam.com/specs.php). However, there is a significant bird welfare concern given the means of death is reported to be via occlusion of the respiratory tract.

Given that neither whole house gassing with carbon dioxide nor fire fighting foam would appear to be entirely satisfactory for different reasons, it was thought that foam containing pure nitrogen might be a feasible option to kill poultry reared in a much larger range of housing systems (Raj and Hickman, 2006.

It was thought that low water content foam (referred to as dry foam) could be made by using surfactants similar to those employed to manufacture domestic hair shampoo. This could prevent drowning of conscious poultry. It was also thought if the shampoo bubbles contained pure nitrogen and burst due to the movement of birds or upon contact with their feathers, the dry foam could release the gas at bird levels producing acute anoxia, or deplete atmospheric oxygen and create acute hypoxia that would be adequate to kill birds. In this regard, it is known that a residual oxygen level of less than 2% by volume would be adequate to render poultry unconscious within a matter of seconds leading to death within two minutes.

7. Adverse effects of animal welfare hazards during stunning and killing

The adverse effects of animal welfare hazards have several aspects (e.g. pain and fear), which can be assessed separately and possibly on different scales. Such components used in various RAs have been the following:

- Pain
- Fear
- Anxiety
- Frustration
- Behavioural disruption
- Malaise
- Thirst
- Hunger
- Discomfort

These are all different aspects of welfare, some of which are not used at slaughter and killing, and which together, in some way, contribute to the total level of welfare. When setting out to assess and measure welfare, however, comparing values will become complicated as they are scored on different scales. The different components of welfare effects are listed and defined below.

7.1. Pain

In human medicine, pain has been defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or has been described in terms of such damage (Merskey, 1964). According to Broom and Johnson (1993), pain in animals is an aversive sensation, usually involving specialized nociceptive neurons, and often some degree of tissue injury, but not any higher level brain processing. However, emotional modulation through the involvement of cortical structures of the brain must not be excluded. Pain normally elicits protective motor and autonomic reactions, results in learned avoidance behaviour, and modifies social and other behaviour. Detection and assessment of pain relies upon a combination of behavioural and physiological indices, such as alterations in motor activities, escape, freezing behaviour, aggression, increased heart and breathing rates, and elevated levels of stress hormones (Flecknell and Molony 1997).

7.2. Frustration

The emotional perception of the situation in which an animal is motivated to perform a certain behaviour that, however, is thwarted by external circumstances (e.g. lack of space) or the environment does not provide the necessary conditions (e.g. no litter for scratching, no roughage to eat) (Duncan and Fraser 1997).

7.3. Distress and stress

In medicine, distress is stress caused by adverse events. Distress is an emotional and and physical response to threats from the outside world. Common stress reactions include muscular tension, irritability, inability to concentrate, and a variety of physical symptoms, such as headaches and an accelerated heart rate (Jones, 1997).

7.4. Fear

Fear is an adaptive aversive emotional state with fear behaviour functioning to protect the animal from injury. In contrast to anxiety, it is based up a real, rather than imaginary threat. (Jones, 1997)

7.5. Anxiety

Anxiety is a multisystem response to a perceived threat or danger (Boissy, 1995). It reflects a combination of biochemical changes in the body, the patient's personal history and memory, and the social situation. As far as we know, anxiety is a uniquely human experience. Other animals clearly know fear, but human anxiety involves an ability, to use memory and imagination to move backward and forward in time, that animals do not appear to have. Although anxiety is related to fear, it is not the same thing. Fear is a direct, focused response to a specific event or object, and the person is consciously aware of it. Most people will feel fear if someone points a loaded gun at them or if they see a tornado forming on the horizon. They also will recognize that they are afraid. Anxiety, on the other hand, is often unfocused, vague, and hard to pin down to a specific cause.

8. Assessment of animal welfare risks during stunning and killing

8.1. Risk assessment methodology

8.1.1. General considerations

A risk assessment methodology similar to earlier work carried out by EFSA workgroups was applied. This involved constructing risk tables including estimates for hazard characterization, hazard exposure, and overall risk as a consequence of hazards. The principal reason for the choice of method was that considerable experience and skill has been gained through earlier work using the same approach. In fact, there is no other developed method available.

When performing a risk assessment, this should be in response to a risk question posed by a risk manager. If the risk question is too general, the risk assessment might not give very precise answers because the target populations, the hazards and the exposure scenarios might be too numerous for an in-depth risk assessment given the resources to perform the assessment. Regarding stunning and killing of animals, there are numerous species, methods and situations involved. Therefore, only a few examples can be given to illustrate the methodological aspects of such risk assessments.

8.1.2. Selection of species for RA tables

Risk assessment can be carried out in an exhaustive manner using extensive details for each species. However, in order to make meaningful assessments within the scope of this project, it was decided to select a limited number of species for which hazards were listed. To represent commonly slaughtered animals, cattle, pigs, broilers and turkeys were chosen. In addition, deer and salmon were selected for game, and rats for laboratory animals.

8.1.3. Hazard identification and characterization

Preparation of the lists of potential hazards to welfare at stunning and killing was conducted by the inclusion of experienced researchers from three different disciplines, each researcher carrying out a careful review of the available scientific literature in his/her area. Subsequently, hazards were proposed and discussed at length by the project team, and consensus was reached on the type of adverse effects caused by each hazard, i.e. which were the welfare components affected, and which of those welfare components were the most prominent.

It was decided that hazard identification and characterization for each selected species should start at the point of unloading at the abattoir and cover possible scenarios of preslaughter handling including passage through raceways, restraint, stunning and slaughter. Referenced publications on preslaughter handling of cattle and pigs included Grandin and Regenstain (1994), Troeger et al. (1994), and Grandin (website, 2002, 2003). Similarly, relevant publications on fish handling were Mitton et al. (1994), Erikson (2002), and Robb and Kestin

(2002), and on poultry Duncan et al. (1986), Gregory and Wilkins (1989), Berg and Sanotra (2001), and Sanotra et al. (2001). Tables 8.3 to 8.8 summarize information on commonly used systems and methods, and on factors that affect welfare for given species during different stages of stunning for slaughter or killing procedures. This information was used to construct the risk tables in Appendix 1.

The severity of adverse effects was scored on a 5-level scale (Table 8.1; see also Chapter 7). Negligible effects (level 0) were not considered further. The duration of adverse effects was estimated on a continuous scale, expressed in minutes.

Table 8.1. Severity scores of adverse effects.

Severity of adverse effect	Descriptive definition	Score
Critical	Extreme changes from normality and indicative of pain, malaise, fear or anxiety, that if persist would be incompatible with life	4
Severe	Involving explicit pain, malaise, frustration, fear or anxiety; strong stress reaction, dramatic change in motor behaviour; vocalization may occur	3
Moderate	Some pain, malaise, frustration, fear or anxiety; stress reaction, some change in motor behaviour; occasional vocalization may occur	2
Limited	Minor pain, malaise, frustration, fear or anxiety; physiological effects may be recorded as well as moderate behavioural changes	1
Negligible	No pain, malaise, frustration, fear or anxiety	0

The probability of adverse effects occurring at exposure to the hazard was estimated quantitatively as a Pert probability distribution function, specifying minimum, most likely and maximum values. Qualitative assessment of the uncertainty of adverse effects was done by applying the scores in Table 8.2. The uncertainty was indicated as high, medium or low. Each score definition was discussed by colleagues in the project team and agreed. Scores were considered, modified if appropriate, and agreed between experts involved in the exercise.

Table 8.2. Qualitative uncertainty scores for adverse effects at exposure to hazards, for exposure to hazards, and for risk estimates.

Score	Descriptive definition	Score
High	Based on scarce, unpublished or inconsistent data, personal communication, experience or informed opinion	3
Medium	Based on scarce or somewhat inconsistent scientific data, or on solid and complete data for other species	2
Low	Based on solid, complete and consistent data from multiple scientific publications	1

8.1.4. Exposure assessment

The probability of exposure to the hazard was estimated quantitatively as a Pert probability distribution function, specifying minimum, most likely and maximum values, similar to the assessment of the probability of adverse effects. Qualitative assessment of the exposure was done by applying the scores in Table 6.2.

8.1.5. *Risk characterization*

From the probability distribution of hazard exposure, the probability distribution of adverse effects occurring at exposure to hazards, and the severity and duration of adverse effects when occurring the risk of adverse effects was estimated and expressed as a point estimate with a 95% confidence interval. Risk estimation was done using the @Risk add-in software in Microsoft Excel and Monte Carlo simulation. Qualitative assessment of the risks was done by applying the scores in Table 8.2.

8.2. Risk estimates

Final risk estimates are found in Appendix 1. Presented risk estimates are unitless. The figures depend on the scales of underlying estimates and therefore can not be compared with figures from other publications. However, because the same estimation procedure has been used consistently throughout this report, the estimates can be compared across species and hazards.

Table 8.3. Commonly used systems and factors that affect animal welfare during stunning for slaughter or killing of selected species.

	Pen	Passageway	Race into stunning area	Restraint	Stunning box
Bulls	Familiar groups Mixing reduces welfare	Single file race	Curved/straight race	Head restraint/yoke or free standing	For captive bolt or electrical stunning
Pigs	Familiar groups Mixing reduces welfare	Group of max 5, single/double file in race	Group or single/double file	Automatic conveyors, v-type, mono-rail Automatic moving gates (CO_2)	Free, standing in pen or manual stunning on exit from a restraining conveyor
Broilers	crates			Hanging on shackle or moving modules	
Turkeys	crates			Hanging on shackle	
Rat	group			Manual restraint by hand	
Salmon	group		Can be pumped out	Manual restraint by hand	
Deer	group			Free, standing in field	

Table 8.4. Methods for stunning for slaughter or killing of selected species; XXX, preferred; XX, commonly used; X, infrequently used.

	Electrical			Mechanical				Gas		
	Head-only	**Head to body**	**Automatic**	**Blow on head**	**Captive bolt**	**Free bullet**	**Microwave**	**CO_2**	**Inert N_2/Ar**	**Mix CO_2**
Bulls	XX		X	X	XXX	X				
Pigs	XX	XX	XX					XX		X
Broilers		XX						XX		X
Turkeys		XX						X		X
Rats							X	X		
Salmon		XX		XX (Priest)				X		
Deer						XXX				

Table 8.5. Methods for stunning for emergency killing of selected species; XXX, preferred; XX, commonly used; X, infrequently used.

	Electrical		Mechanical		Physical		Gasses	
	Head to body	**Automatic**	**Captive bolt**	**Free Bullet**	**Neck dislocation**	**Heating/cooling**	**Mix CO_2**	**Inert**
Bulls	X		XXX	XX				
Pigs	XXX	X	X					
Broilers	X	X			XX		XX	XX
Turkeys	X	X					XX	
Rat					X	X	X	
Salmon		XX				XX	X	
Deer				XXX				

Table 8.6. Methods for stunning for killing of selected species for disease control; XXX, preferred; XX, commonly used; X, infrequently used.

	Electrical		Mechanical		Physical		Gasses		
	Head to body	**Automatic**	**Captive bolt**	**Free Bullet**	**Neck dislocation**	**Heating/cooling**	**Mix CO_2**	**Inert**	**Foam**
Bulls	X		XXX	XX					
Pigs	XX	X	XX				X		
Broilers		XX			XX		XX	XX	X
Turkeys	X	X					XX		X
Rat					X	X			
Salmon		XX				XX	X		
Deer				XXX					

Table 8.7. Stunning methods in common slaughter species; X, method used.

	Blow on head	Electrical 50 Hz			Captive bolt		Free bullet/ rifle	CO_2	Other gases N_2/Ar	Novel methods[a]	
		Manual head only	Auto head-to-back	Auto head only	Penetrating	Non-penetrating				Water jet	Magnetic stunning
Cattle		X	X[b]	X	X	X					
Calves		X	X	X	X						
Pigs		X	X	X	X and emergency for casualties in abattoir			X or with anoxic/inert gases	X		
Sheep		X		X	X and emergency for casualties in abattoir						
Deer							X high neck				
Broilers		X		Water bath				X or with anoxic/inert gases	X		
Turkeys				Water bath							
Rabbit	X	X			X						
Duck/ geese				Water bath							
Ostrich		X			X						
Buffalo					X						
Horses					X		X				
Wild boar							X				
Fish	X			X in		X		X in water			

	water			

[a] Under development, not in commercial use.
[b] Not practical for use on farm; can be used if available.

Table 8.8. High frequency electrical stunning in selected species; X, method used.

	Electrical >500 Hz			
	Manual head only	**Manual head-to-back**	**Auto head only**	**Auto stun-kill**
Pigs	X	X with 50 Hz on chest for cardiac arrest		X with 50 Hz on chest for cardiac arrest
Sheep	X			
Broilers	X		X	
Turkeys	X		X	

9. Discussion

9.1. Animal welfare considerations

In animal welfare risk assessment, the (potential) effects of hazards on overall welfare of animals have to be quantified, i.e. the degree to which animals fail to cope with a specific hazard must be expressed in quantitative terms. Failure to cope might result in disease or injury, but also in adverse states like pain, fear and frustration. At the other extreme, we might identify positive results of successful coping such as agility, joy or even happiness. These are all different components of welfare which together, in some way, contribute to the overall level of welfare. When setting out to assess and measure welfare, however, we run into the difficulty of comparing values on different scales. Moreover, different hazards affect generally specific components of welfare and i.e. impairment with respect to one component of welfare is generally not accompanied by the same deterioration in all other aspects. The list of possible situations with incongruent welfare aspects is in fact practically endless. An animal might suffer from pain but still experience happiness, or it can be perfectly healthy but still feel frustration. How are we then to weigh these different components against each other, and how do we decide in which case the overall welfare is worst?

Obviously, many concepts can be dissected into different components. For example, a certain disease can be described as consisting of the presence of micro-organisms in the body, pathological changes in affected tissues, secondary bodily changes like fever or leucocytosis, signs of inflammation of organs or limbs, the animal's subjective experience of the disease, and so on. All these components of disease manifest themselves in a different ways and are established and measured differently. We can still measure some of them and summarize our findings to an overall assessment of the disease status, but it will always be a matter of choice how we do this. To deal with the concept in question – being disease or welfare – we should clearly base are choice of methods on available scientific knowledge. It is also relevant that methods allow a clear communication and can easily be understood by others.

Following the above, we acknowledge that animal welfare has several components, which can be assessed separately and often on different scales. In the context of the relatively short slaughter process, some of the components seem more relevant to consider than others. Most relevant seem negative emotional states like pain, distress, fear and frustration, as well as physical injuries. Ideally, a separate risk assessment should therefore be carried out for each of these components, and the different results communicated to the risk manager. In practice, for obvious reasons, this is hardly feasible and risk managers obviously want to deal with 'overall welfare', particularly when communicating risks to stakeholders. In this project, we have chosen a compromise, performing the risk analysis exercises on a total welfare measure, derived from an implicit and rather subjective summary of important components, while indicating the most pertinent welfare components in play for a selection of individual hazards.

From our definition of animal welfare (see Chapter 2) follows that death itself is not related to welfare, i.e. an animal's welfare is not compromised by its dying. Events can only influence welfare as long as the animal is alive, either at a farm or at an abattoir during unloading, lairage, driving, restraint and stunning. Nevertheless, a high death rate in a group of animals can be indicative of a welfare problem, either because the animals die spontaneously and suffer reduced welfare until they do, or because they are killed prematurely to avoid prolonged suffering. If the animals are killed before suffering occurs, such as in the case of overstocking growing animals, welfare is not compromised, although the farming or handling conditions might be clearly deficient. Slaughter can indeed be regarded as premature killing of (ideally) healthy animals, which could often have lived much longer. It thus prevents the animals from realizing their full life potential. Some people might regard this as problematic or unethical but, given our definition, it does not affect their welfare.

9.2. Methodological aspects of an Animal Welfare Risk Assessment

Risk questions related to animal welfare risk assessments have hitherto usually been formulated in very general terms (e.g. risks of poor welfare during rearing of calves, risks of poor welfare during rearing of fattening pigs). As a consequence, the RA generated was not of the same format (ranging from condensed to extremely elaborate) and not necessarily considered optimal from the perspective of the risk manager or legislator. Majala (2006) points out that when commissioning a risk assessment it would be useful to adhere to a general format where e.g. the purpose of the RA, the type expected (quantitative or qualitative), possible control options, content of RA and exclusions are clearly identified by the risk manager and agreed upon between the risk manager and the risk assessors.

The exercise carried out here clearly shows that when considering stunning and killing of animals, the area is extensive and complex. Thus, risk questions may be limited to risks e.g. in association with a specific stunning procedure of a specific species, the risks at lairage before slaughter of a specific animal species, the risk of using electric goads at driving an individual of a specific species, or risks of different driving systems for defined species. A formalised procedure of interaction between risk manager and risk assessor (see e.g. Majala, 2006) may prove beneficial for future animal welfare risk assessment exercises.

At any given moment, the animal's bodily and mental state is a result from inherent characteristics (e.g. breed, age) as well as experiences, including earlier conditions of housing, transport and handling. The individual's state will influence its needs and thus susceptibility to hazards, and is hence relevant for the consequences of a hazard for its welfare. Obviously, these needs will change over time, and sometimes dramatically so. If the individual needs are not considered separately, they will be observed in the population as an increased variation (between individuals and over time) in the species-specific needs. Factors that can be suspected to influence the susceptibility to hazards are breed, age, body condition, pregnancy and earlier cognitive experience (memories) and welfare status.

The process from unloading to killing of the animals at the abattoir (or during hunting of wild animals) can be divided into several phases such as, unloading, lairage (not always applied), driving to stunning area, preparation for stunning, stunning, and killing. During each phase, the animals are exposed to hazards and run a risk of reduced welfare, in terms of one ore more of its different components. At the start of each phase (including at unloading), each animal has a certain status which will affect its susceptibility to hazards. For example, lame animals will have difficulties to walk fast and they might suffer from standing for a long time on hard flooring – even though the lameness was caused by poor housing conditions at the farm, possibly long before slaughter.

Not to reduce animal welfare unnecessarily, the slaughter process should either be flexible enough to handle all sorts of animals according to their individual needs, or account for important individual characteristics by applying separate production lines or slaughter techniques. For instance, in the previous example of lame animals, it might be argued that such animals should not be slaughtered using the same routines as healthy conspecifics in order to meet their needs and prevent high welfare risks.

9.2.1. Particular problems associated with Uncertainty Analysis

An intrinsic part of risk assessment (RA) is the estimation of the degree of uncertainty of various model inputs, assumptions and of structure/form (CAC 2002). In exercises dedicated to the assessment of animal welfare published data supporting a quantitative (or semi-quantitative) analysis are not always available or scarce. Hence, in general, the RA of animal welfare has a largely qualitative character, i.e. data (informed opinions) are solicited from scientists active in [or associated with ('consultants')] the RA working group who are particularly knowledgeable in the area and the formulation of a joint 'expert' opinion is sought.

Two principal factors of uncertainty influence the outcome of RA, i.e. the likelihood of an individual animal's welfare being adversely affected assuming exposure to the particular hazard, and the proportion of the animal population subjected to the hazard in a geographical region under a certain specifically defined scenario of animal production (or further processing). The former is generally assessed by scrutinising scientific studies published in high quality, peer-reviewed publications, whereby the degree to which the results are corroborated in studies by fellow-scientists determines the correctness (certainty) of the final statement. Inherent to the general nature of scientific publications on animal welfare, few if any published data are available on the degree of exposure of animal populations to a particular hazard. In addition, one must realize that i) considerable differences in exposure exist across Europe, dependent on the various animal production or processing systems and ii) that welfare experts involved in a particular area are not necessarily aware of the situation outside their immediate activity arena.

Also, the scientific arguments underpinning a *consensus* opinion of experts have not necessarily been published in the literature, either because these are sometimes considered to be 'too obvious' to be specifically included in a scientific publication or because few if any other scientists, beside those already involved in RA, are active or have published in the specific field of research.

In the underlying report on the welfare aspects of stunning and killing of animals the afore-mentioned particularly applies: few scientists world-wide are active in studying welfare aspects of stunning and killing. Consequently relatively few publications are available and reliable documents on the exposure of animals in Europe to the prevailing systems are scarce.

Regardless the credibility of experts *per se,* the risk assessor exclusively relying on the ‘experience’ of few has by consequence of the fundamental principles of RA (science-based; well documented, objective, repeatable, transparent) no other option than to attribute a high uncertainty score for many hazards and exposure rates. This will inevitably lead to a number of hazard entries ultimately generating risk estimates with a level of uncertainty which in the perception of some experts’ is higher than justified.

9.3. Risk management options

Risk management is using risk assessment in decision making to prevent, in this case, animal welfare problems. Obviously, the set of measures to assess welfare must address all important welfare criteria.

The Welfare Quality® (WQ) project aims to deliver welfare assessment systems for several species as well as accepted procedures for the standardized conversion of welfare measures into accessible and understandable product information. The focus within the WQ project is to measure parameters at the animal level that reflect the actual welfare state of the animals. Such animal-based measures (or ‘output measures’) include the effects of variations in management systems as well as the effects of specific system-animal interactions.

In WQ twelve welfare criteria, grouped under four principles, were identified (Keeling and Veissier, 2005; Veissier and Evans, 2007).

After a first analysis these criteria seemed to be applicable for slaughterhouse conditions as they cover the welfare concerns under such conditions. Some criteria are only relevant for lairage conditions (e.g. 1, 2, 3, 4) where the other have wider relevance. Criterion 7 is considered less relevant as disease is not really caused by hazards in the slaughterhouse. However, disease should be considered as a characteristic of the animal upon arrival and may predispose for other hazards (or the effects of hazards in the slaughterhouse may be more severe for such animals). Examples of potential measures are presented in Table 9.1.

Table 9.1. Welfare principles, criteria and potential measures identified in Welfare Quality®.

Welfare Principles	Welfare Criteria	Meaning	Examples of potential measures
Good feeding	1. Absence of prolonged hunger	Animals should not suffer from prolonged hunger	Body condition score
	2. Absence of prolonged thirst	Animals should not suffer from prolonged thirst	Presence of drinker and routine for checking function
Good housing	3. Comfort around resting	Animals should be comfortable, especially within their lying areas	Frequencies of different lying positions, standing up and lying down behaviour
	4. Thermal comfort	Animals should be in good thermal environment	Panting, shivering
	5. Ease of Movement	Animals should be able to moving around freely	Slipping or falling
Good health	6. Absence of injuries	Animals should not be physically injured	Clinical scoring of integument, carcass damage, lameness
	7. Absence of disease	Animals should be free of disease.	Enteric problems, downgrades at slaughter
	8. Absence of pain induced by management procedures	Animals should not suffer from pain induced by inappropriate management	Evidence of routine mutilations such as tail docking, dehorning, stunning effectiveness at slaughter
Appropriate behaviour	9. Expression of social behaviours	Animals should be allowed to express natural, non-harmful, social behaviours.	Social licking, aggression
	10. Expression of other behaviours		Play, abnormal behaviour
	11. Good human-animal relationship		Approach and/or avoidance tests
	12. Absence of general fear		Novel object test

9.3.1. *On Risk Management according to HACCP principles*

Although the major thrust of this report is to provide an overview of the hazards and the related risks to welfare of animals associated with their stunning and killing (i.e. risk assessment; RA), the project group aimed to also provide documented support for risk management (RM) options of these risks. Analogous to the approach chosen when applying the principles of RA, as defined by the Codex Alimentarius, to animal welfare, it was considered how the principles of the widely used Hazard Analysis Critical Control Point (HACCP) system (Codex Alimentarius, 2001) could serve a similar purpose for the welfare management of animals in general, and more in particular during their stunning and killing.

9.3.2. *HACCP – general principles*

Various options for the management of risks exist, most notably the Hazard Analysis Critical Control Point (HACCP) system as explicitly suggested in European legislation for achieving food safety (e.g. European Commission, 2002, 2004a, 2004b, 2004c). In suggesting the adoption of HACCP as a useful approach, (be it targeted at food safety or animal welfare; see later), it is essential to realise that this only makes sense provided basic measures of quality and safety assurance are adhered to first. The latter are commonly called 'Good Practices' [e.g. 'Good Farming Practices' (GFP), 'Good Veterinary Practices' (GVP), 'Good Manufacturing Practices' (GMP, principally addressing the technical aspects of the whole production process), 'Good Hygiene Practices' (GHP, concentrating on hygiene aspects of production) or – *mutatis mutande* – as applicable to the contents of this report - 'Good Stunning/Killing Practices' (GSKP)]. All these describe the 'best practices' that are universally applicable based on scientific, well-documented proof, and which represent absolute prerequisites. They serve as the 'fundaments' of risk management, in that they principally prevent external hazards being introduced in a production environment. Additionally relying on a HACCP system essentially serves to significantly reduce or even eliminate those hazards that, despite strict adherence to best practices, may still prevail.

This concept, repeatedly stressed in the literature on quality and safety assurance (e.g. ICMSF, 1988; Mayes and Baird-Parker, 1992, NACMCF, 1998, Buncic, 2006, Smulders, 2007), has been discussed by Untermann (1998) who compared the HACCP risk management system with a house, where Good practices and adequate structural facilities represent its fundaments and walls without which the 'HACCP roof.' would collapse. In addition, Fellner and Riedl (2004) have extended this concept by stressing that truly effective 'longitudinal' risk management according to HACCP principles can only be realised by integrating the various risk management efforts all along the production chain. Consequently, such an approach is compared with a row of houses (the various subsequent links of the production chain) with a common HACCP roof. In terms of food animal production this means that for each link in the chain a HACCP system is adopted concentrating on those risks that cannot be eliminated further down the line and assuring that the joint efforts of the various links generate the best possible result.

HACCP was principally developed for purposes of food safety assurance and is based on 7 principles (CAC, 2001, FAO/WHO 2003), viz:

1. Conduct a **Hazard Analysis** (Hazard Identification and Hazard Characterisation)
2. Determine **Critical Control Points** (CCP's, i.e. carefully determine at which point in production hazards can be significantly reduced (CCP-2) or even eliminated (CCP-1)
3. Determine **Critical Limits**, i.e. define criteria above of beneath which the situation is acceptable/unacceptable
4. Adopt a system for **Monitoring** whether or not the CCP is in check
5. Establish the **Corrective Action** necessary when CCP's are not under control
6. Take measures for **Verification** if the HACCP system functions
7. Establish a reliable procedure for **Documentation** that shows that all the above principles and associated protocols have been taken into consideration.

It is also important to realise that a properly executed HACCP is characterised by the following:

1. It is **systematic,** i.e. following a structured approach and considering all relevant factors, thereby assuring that nothing is overlooked
2. It is **product-specific,** i.e. only targeted at one specific product
3. It is **hazard-specific**, i.e. only addresses the hazards that are associated with the specific product (see 2) and a particular situation (see 4 and 5)
4. It is **process-specific**, i.e. considers only the hazards associated with a well-defined way of processing.
5. It is **enterprise-specific**, i.e. considers only the circumstances of a particular processing unit

It is important to appreciate the difference between risk assessment and HACCP (a risk management system). Only provided the former is available can an HACCP team take a decision on whether or not a hazard may constitute a risk which consequently should be properly managed. Whereas in some cases risk assessments are available to the HACCP team from literature, in other cases these need to be conducted by the team itself. In summary: RA is an integral part of the HACCP system, HACCP is not an element of RA.

HACCP applied in primary animal production including for purposes of animal welfare management

Whereas the HACCP system is well-established for risk management in food processing, one has only begun to introduce it in primary animal production, largely because its full application still meets with methodological difficulties (e.g. how can verification and auditing be achieved?, how can the system be applied in an economic way?, how to assure a longitudinal approach including all relevant links of the production chain? (Sofos, 2002). In the realisation that HACCP in the ante mortem production phase is still "work in progress" the European legislature has not (yet) made HACCP – in the strict sense of the concept - mandatory for primary production. However, in European legislation (e.g. European Commission, 2002, 2004) member states are prompted to adopt "HACCP-like" plans to meet the issues of food safety, public health and animal health and –welfare. Consequently, many such plans suggested in literature are still largely based on adhering to Good Practices (e.g. see Noordhuizen et al., 2008)

For purposes of using the HACCP concept in the area of welfare management, the food-related terminology needs to be adapted. This could essentially be achieved by defining hazards as factors adversely affecting animal welfare and exchanging the words ‘product’ and ‘process’ for (a particular) ‘animal species’ and (a particular) ‘animal handling procedure’ (e.g. a husbandry-, transport-, lairage- or stunning/killing system).

In consideration of the above, the authors of this report acknowledge that i) an HACCP approach for the management of welfare risks related to stunning and killing whilst disregarding the potential of risk management measures taken during a preceding ante mortem (notably the transport) phase will not result in the desired optimal result, and ii) many hazards occurring from unloading to stunning/killing can be effectively prevented through adhering to Good Practices (i.e. assuring that proper infrastructure, equipment and professional behaviour prevail),

In Tables 9.2 to 9.16, the latter have been included in the columns ‘Do’s’ and ‘Don’ts’. Where application of the HACCP system conforming to the above-mentioned 7 principles and 5 characteristics is deemed feasible CCP’s have been indicated as such.

In attempts to introduce HACCP-like risk management approaches for welfare hazard prevention in the stunning/killing area, the terminology needs to be adapted. The key characteristics of HACCP [systematic, product- (i.e. animal species-) specific, hazard- (i.e. welfare-) specific, process- (i.e. stunning/killing system-) specific and enterprise (i.e. abattoir-) specific] were considered carefully.

Consequently, only 1 animal species (bulls) was selected as an example of how the information provided in the RA part of this report can be used for purposes of risk management *(‘species-specific’*).

Various potential welfare risk areas (which together comprise the entire stunning/killing process) were described for *‘specific stunning systems’*. In the tables below these were included as separate cells. The *‘specific welfare hazards’* associated with each system (i.e. those previously systematically identified by way of RA with a further description of the adverse effects added under the column: ‘Factors’) were listed for a *‘specific abattoir’*.

For the identification of welfare management options a distinction was made between those measures that together comprise the *‘Good Stunning/Killing Practices’ (GSKP’s*, i.e. those measures that relate to *proper infrastructures, equipment or professional behaviour)* and those that can be considered *‘Critical Control Points’ (CCP’s;* i.e. those that are *monitorable, correctable, verifiable and documentable)*. To this end for all hazards 2 columns (Do’s and Don’ts) were included and assessed whether these represented GSKP’s or CCP’s. To substantiate this delineation a column was added for further explanation where necessary.

Table 9.2. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; unloading bay to lairage.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Driveway design	Curvature[a]		>120 º	GSKP	
	Width, single file[a]				
	Width, multiple file[a]				
	Sharp protrusions and dead ends[b]	Take corrective action	No sharp protrusions	GSKP	**CCP**
Structure of driveway sides	Sharp objects, partially open sides, short sides		No sharp protrusions	GSKP	
Floor surface and condition	Slipperiness, gaps, potholes, steps, too rough[b]	Take corrective action, Clean, add straw/sawdust/sand/grit	Do not allow slippery material to build up		**CCP**
Slope of the floor	too steep, up/down[a]	Slight incline <30 º	>30 º decline		**CCP**
Gates	Design (vertical or horizontal opening, opening size)[a]	Smooth operation, use buffers	No metal clanking noise	GSKP	
Sensory input (Sound Smell Light)	Glaring objects, noise from gates, light intensity, sudden change of light, hissing noise[b]	Cover, hide, rubber silencers, modify light, reduce/eliminate noise		GSKP	**CCP**
Air quality	Noxious gasses (3 ml/L CO_2; 0.02 ml/L NH_3), draught, temperature (not >30 ºC), humidity (not >80%)[b]	Modify air flow/temperature	>30 ºC, 80% humidity, 3000 ppm CO_2 , NH_3 10 ppm	GSKP	**CCP**
Handlers	Hitting	Instruct to stop practice, provide training(long-term)	Do not allow hitting,employ trained personnel'	GSKP	**CCP**
	Shouting	Instruct to stop practice, provide training(long-term)	employ trained personnel'	GSKP	**CCP**
	Untrained handlers, lack of motivation	Instruct to stop practice, provide training(long-term), increase motivation	employ trained personnel'		
Use of driving tools	Use of prods, electric goads, sticks	Replace by soft implements	Do not allow excessive use of prods	GSKP	
Animal throughput	High speed	Reduce throughput if welfare compromised	Do not maintain high throughput if welfare poor		**CCP**

[a] Fixed designs.
[b] Some may be fixed, some modifiable.

Table 9.3. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; holding pen.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Height and dimensions	Appropriate for animal size		Do not not overcrowd		**CCP**
Structure of pen	Solid sides,partially open sides, short side, sharp objects,	Check obstacles, avoid overcrowding	Do not not overcrowd	GSKP	
Floor surface and condition	Slipperiness, gaps, potholes, steps, too rough,	Provide rough surface	Do not allow slippery material to build up	GSKP	
Bedding	Available, unavaliable, wet, dirty, faecal contamination	provide bedding	Do not allow dirty/faecal material to build up	GSKP	
Gates	Design (vertical or horizontal opening, opening size), gate handle type	Reduce noise, fit buffers	Reduce clanking noise	GSKP	
Sensory input	Smell,glaring objects, light intensity, sudden change of light, overall noise	Provide adequate lighting, avoid dark areas	Avoid dark areas,	GSKP	
Air quality	Noxious gasses, weather conditions, ventilation, temperature (high or low), humidity	Improve ventilation		GSKP	
Handlers	Hitting, shouting	Instruct to stop practice, provide training(long-term)	Do not allow hitting, employ trained personnel'		**CCP**
	Untrained handlers, lack of motivation	Instruct to stop practice, provide training(long-term)	Do not employ untrained personnel		
Use of driving tools	Use of prods, electric goads, sticks,	Instruct to stop practice, provide training(long-term)	No Electric goads employ trained personnel'	GSKP	
	Rattles, soft brushes, automatic gates and transfer			GSKP	
Stocking density	Overcrowding (Standard 500 to 600 kg/m2)		Do not Overcrowd/ employ untrained personnel	GSKP	**CCP**

Mixing	Aggression, fighting, mounting behaviour	Keep groups together employ trained personnel'	No mixing	GSKP	**CCP**
Drinker availability	No drinkers available	Provide Drinkers			
Food availability	No food available	Provide Food			

Table 9.4. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; passageway.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Dimension and design of driveway	Curvature, Sharp angles, width		No Dead ends,no dark areas	GSKP	
Structure of driveway sides	Sharp objects, partially open sides, short sides	Solid sides	No sharp protrusinons, reflections, gaps		
Floor surface and condition	Slipperiness, gaps, potholes, steps, too rough,	Rough surface	Do not allow slippery material to build up	GSKP	
Angle and design of floor	Too steep, up/down, steps	Slight incline		GSKP	
Gates	Design (vertical or horizontal opening, opening size)[a]	Reduce clanking noise	Avoid metal clanking noise		
Sensory input (Sound Smell Light)	Glaring objects, noise from gates, light intensity, sudden change of light, hissing noise	Reduce noise, provide good lighting	Reduce noise, reflections	GSKP	
Air quality	Noxious gasses, draught, temperature (high or low), humidity	Improve ventilation		GSKP	
Handlers	Hitting	Instruct to stop practice, provide training(long-term)	No hitting		**CCP**
	Shouting	Provide training	Avoid shouiting		
	Untrained handlers, lack of motivation	Instruct to stop practice, provide training(long-term)		GSKP	
Driving system	Uncontrolled system if automatic,inadequate handling if manual	Instruct to stop practice, provide training(long-term)		GSKP	
Non return gates	Faulty operating gates	Provide training, use soft implements, reduce stress		GSKP	

Moving into single file	Funnelling and jamming, balking	Provide training, use soft implements, reduce stress	Avoid coersion, do not stress animals unnecessarily	GSKP	
Continuity of race	Dead ends		No Dead ends,no dark areas	GSKP	

[a] Some may be fixed, some modifiable.

Table 9.5. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; race into stun area.

Hazards from RA	**Factor**	**Dos**	**Don'ts**	**GSKP**	**CCP**
Dimension of driveway	Curvature, dead end, Sharp angles, width		No Dead ends,provide overhead lighting		**CCP**
Structure of driveway sides	sharp objects, partially open sides, short sides	Provide continuity with no dead ends	No gaps, reflections	GSKP	
Floor surface and condition	Slipperiness, gaps, potholes, steps, too rough,	reduce slipperiness	No , dead ends, sharp contrast, glaress	GSKP	
Slope of the floor	Too steep, up/down,	slight incline			
Gates	Design (vertical or horizontal opening, opening size)	Reduce clanking metal noise	No meatl clanking noise	GSKP	
Sensory input (Sound Smell Light)	Glaring objects, noise from gates, light intensity, sudden change of light, hissing noise		No Glares, dark from light	GSKP	
Handlers	Hitting	Instruct to stop practice, provide training(long-term)			**CCP**
	Shouting	Instruct to stop practice, provide training(long-term)		GSKP	
	Untrained handlers, lack of motivation	Instruct to stop practice, provide training(long-term)		GSKP	
Use of driving tools	Use of prods, electric goads, sticks	Instruct to stop practice, provide training(long-term),	Do not use welfare compromising tools	GSKP	

Animal throughput	High speed	Optimise			**CCP**

Table 9.6. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during restraint.

Hazards from RA	**Factor**	**Dos**	**Don'ts**	**GSKP**	**CCP**
Dimension and design	Sharp objects, width, length, height	Use stress free designs		GSKP	
Floor type and design	Slippery, obstacles, too rough,		Do not allow slippery material to build up	GSKP	
Restraint devices	Improper design head restrainer, belly plate, rump push	Head restraint or object under neck	Do not use welfare compromising tools/devices		**CCP**
Sensory input	Light intensity, overhead lighting, noise	Overhead light for keeping head up		GSKP	
Operator	Hitting	provide training	No hitting		**CCP**
	Shouting		Do not use welfare compromising tools/devices	GSKP	
	Untrained handlers, lack of motivation	Provide training		GSKP	

Table 9.7. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for slaughter; captive bolt.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)		GSKP	
Gun	Poorly maintained, unsuitable for species, breed and size, malfunctioning, no back-up stunner	Ensure regular maintenance and checks, provide training			**CCP**
Cartridge	Incorrect strength, grain size	Ensure correct cartridge chosen for size		GSKP	
Shooting position	Inaccurate target area and angle	Ensure correct position and traget, provide training	Do not allow incorrect shooting		**CCP**
Air pressure	Insufficient	Check correct pressure	Do not use low pressure	GSKP	
Induction	Successful application	Immediate collapse	Do not continue if recovery signs present		**CCP**
Signs of good stun	Successful application	NO Corneal reflex, NO Rhythmic breathing	Do not continue if recovery signs present		**CCP**
Killing method	Delay before death	Rapid bleed out, cardiac arrest	Do not continue if recovery signs present		**CCP**

Table 9.8. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for slaughter; electricity.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)		GSKP	
Manual equipment	Poorly maintained, unsuitable for species, breed and size, malfunctioning	Instruct to stop practice, provide training(long-term)	Do not use welfare compromising tools/devices	GSKP	
Automatic equipment	Poorly maintained, unsuitable for species, breed and size, malfunctioning	Instruct to stop practice, provide training(long-term)	Do not use welfare compromising tools/devices	GSKP	
Electrical parameters	Incorrect voltage, amperage (1 A), waveform (sinus) , frequency (< 1500 Hz), duration (> 1 s)	Instruct to stop practice, provide training(long-term)	Do not apply insufficient current		**CCP**
Stunning application	Incorrect voltage, amperage (1 A), waveform (sinus) , frequency (< 1500 Hz), duration (> 1 s)	Ensure application to span brain	Do not apply wrong tong placement		**CCP**
Induction	Successful application	Immediate collapse, Tonic/clonic convulsions	Do not allow delayed, incorrect induction		**CCP**
Good signs of stun	Successful application	Observe No breathing, No righting reflex	Do not continue if recovery signs present		**CCP**
Shackling and hoisting	Delay before exsanguination	Ensure shackling immediately after stunning	Do not delay shackling, hoisting		**CCP**
Exsanguination	Incorrect sticking, delayed bleed out	Cut all vessels, long incision	Do not delay sticking		**CCP**

Table 9.9. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for emergency killing; captive bolt.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)		GSKP	
Gun	Poorly maintained, unsuitable for species, breed and size, malfunctioning, no back-up stunner	Ensure regular maintenance and checks, provide training			**CCP**
Cartridge	Incorrect strength, grain size	Ensure correct cartridge chosen for size		GSKP	
Shooting position	Inaccurate target area and angle	Ensure correct position and traget, provide training	Do not allow incorrect shooting		**CCP**
Air pressure	Insufficient	Check correct pressure	Do not use low pressure	GSKP	
Induction	Successful application	Immediate collapse	Do not continue if recovery signs present		**CCP**
Signs of good stun	Successful application	NO Corneal reflex, NO Rhythmic breathing	Do not continue if recovery signs present		**CCP**
Killing method	Delay before death	Rapid bleed out, cardiac arrest	Do not continue if recovery signs present		**CCP**

Table 9.10. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for emergency killing; free bullet.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)	Do not allow incorrect shooting, unqualified people	GSKP	
Gun	Poorly maintained, unsuitable for species, breed and size, malfunctioning, no back-up stunner	Ensure regular maintenance and checks, provide training			**CCP**
Shooting position	Inaccurate target area and angle	Ensure correct application			**CCP**
Killing method	Delay before death	Rapid bleed out, cardiac arrest	Do not continue if recovery signs present		**CCP**
Induction	Successful application	Immediate collapse	Do not continue if recovery signs present		**CCP**
Signs of good stun	Successful application	NO Corneal reflex, NO Rhythmic breathing	Do not continue if recovery signs present		**CCP**

Table 9.11. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for emergency killing; electricity.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)		GSKP	
Manual equipment	Poorly maintained, unsuitable for species, breed and size, malfunctioning	Instruct to stop practice, provide training(long-term)	Do not use welfare compromising tools/devices	GSKP	
Electrical parameters	Incorrect voltage, amperage, waveform, frequency, duration	Instruct to stop practice, provide training(long-term)	Do not use welfare compromising tools/devices		**CCP**
Stunning application	Incorrect target and area, faulty settings	Instruct to stop practice, provide training(long-term)	Do not apply wrong tong placement		**CCP**
Induction	Successful application	Ensure application to span brain	Do not allow delayed, incorrect induction Do not apply insufficient current		**CCP**
Signs of good stun	Successful application	Immediate collapse, Tonic/clonic convulsions, no rhythmic breathing	Do not continue if recovery signs present		**CCP**
Killing method	Delay before death	Ensure shackling immediately after stunning Cut all vessels, long incision	Do not delay shackling, hoisting Do not delay sticking		**CCP**

Table 9.12. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for emergency killing; lethal injection.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, unlicenced, careless	Observe No breathing, No righting reflex	Do not continue if recovery signs present	GSKP	
Drug/agent	Wrong choice, dose	Must be qualified to carry out injection	Do not allow unqualified operators		**CCP**

Injection method	Wrong injection site, missed target, extravascular injection	Must be qualified to carry out injection	Do not allow unqualified operators		**CCP**

Table 9.13. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for disease control; captive bolt.

Hazards from RA	**Factor**	**Dos**	**Don'ts**	**GSKP**	**CCP**
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)		GSKP	
Gun	Poorly maintained, unsuitable for species, breed and size, malfunctioning, no back-up stunner	Ensure regular maintenance and checks, provide training	Do not use poorly maintained gun		**CCP**
Cartridge	Incorrect strength, grain size	Incorrect strength, grain size	Ensure correct cartridge chosen for size	GSKP	
Shooting position	Inaccurate target area and angle	Inaccurate target area and angle	Ensure correct position and traget, provide training		**CCP**
Air pressure	Insufficient	Insufficient	Check correct pressure	GSKP	
Induction	Successful application	Immediate collapse	Do not continue if recovery signs present		**CCP**
Signs of good stun	Successful application	Observe NO Corneal reflex, NO Rhythmic breathing	Do not continue if recovery signs present		**CCP**
Killing method	Delay before death	Rapid bleed out, cardiac arrest	Do not continue if recovery signs present		**CCP**

Table 9.14. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for disease control; free bullet.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)	Do not allow incorrect shooting, unqualified people	GSKP	
Gun	Poorly maintained, unsuitable for species, breed and size, malfunctioning, no back-up stunner	Ensure regular maintenance and checks, provide training	Do not allow use of guns in poor condition	GSKP	
Cartridge	Incorrect strength, grain size	Check cartridge for species/size	Do not use inappropriate cartridge		
Shooting position	Inaccurate target area and angle	Ensure correct application	Do not continue if recovery signs present	GSKP	
Induction	Successful application	Immediate collapse	Do not continue if recovery signs present		**CCP**
Signs of death	Successful application	NO Corneal reflex, NO Rhythmic breathing	Do not continue if recovery signs present		**CCP**
Killing method	Delay before death	Observe no signs of recovery	Do not continue if recovery signs present		**CCP**

Table 9.15. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for disease control; electricity.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, uncertified, careless	Instruct to stop practice, provide training(long-term)		GSKP	
Manual equipment	Poorly maintained, unsuitable for species, breed and size, malfunctioning	Instruct to stop practice, provide training(long-term)	Do not use welfare compromising tools/devices	GSKP	
Electrical parameters	Incorrect voltage, amperage, waveform, frequency, duration	Instruct to stop practice, provide training(long-term)	Do not use welfare compromising tools/devices		**CCP**
Stunning application	Incorrect target and area, faulty settings	Instruct to stop practice, provide training(long-term)	Do not apply wrong tong placement		**CCP**
Induction	Successful application	Ensure application to span brain	Do not apply insufficient current Do not allow delayed, incorrect induction		**CCP**
Signs of good stun	Successful application	Immediate collapse, Tonic/clonic convulsions, no rhythmic breathing	Do not continue if recovery signs present		**CCP**
Killing method	Delay before death	Ensure shackling immediately after stunning Cut all vessels, long incision	Do not delay shackling, hoisting Do not delay sticking		**CCP**

Table 9.16. Good stunning/killing practices (GSKP) and critical control points (CCP) in slaughter cattle; during stunning for disease control; lethal injection.

Hazards from RA	Factor	Dos	Don'ts	GSKP	CCP
Operator	Untrained, unlicenced, careless		Do not allow unqualified operators	GSKP	
Drug/agent	Wrong choice, dose	Choose appropriate drug/dose	Do not allow wrong/insufficient dose	GSKP	
Injection method	Wrong injection site, missed target, extravascular injection	Must be qualified to carry out injection	Do not allow unqualified operators	GSKP	
	Delay before death	Check drug/dose Use back up killing	Do not allow wrong/insufficient dose	GSKP	
Induction	Successful application	Immediate collapse	Do not continue if recovery signs present		**CCP**
Signs of good stun	Successful application	NO Corneal reflex, NO Rhythmic breathing	Do not continue if recovery signs present		**CCP**

10. Conclusions and recommendations

10.1. Conclusions

- Animal Welfare is multi dimensional and principles of good feeding, good health, good housing and appropriate behaviour need to be fulfilled to achieve good welfare. Criteria underlying these principles include for instance absence of prolonged hunger, comfort around resting, thermal comfort, ease of movement, absence of injuries, absence of disease, expression of behaviour, absence of general fear.
- Adverse effects on animal welfare consist of several different components such fear, distress, pain and frustration which can be assessed separately and possibly on different scales. Specific hazards may affect one or more of these components. The combined effects on the different components constitute the overall effect on of a hazard on animal welfare.
- The process from unloading to killing of the animals at the abattoir (or during hunting of wild animals) can be divided into several phases such as, unloading, lairage (not always applied), driving to stunning area, preparation for stunning, stunning, and killing. During each phase, the animals are exposed to hazards and run a risk of reduced welfare, in terms of one ore more of its different components. At the start of each phase (including at unloading), each animal has a certain status (inherent or acquired) which will affect its susceptibility to hazards.
- The condition to be death does not compromise welfare but the preceding period of dying might do so.
- Methodological drawbacks and improvements (see my main conclusions under Chapter 4).
- In transition of RA to RM it is useful that this report includes a number of suggestions (Dos and Don'ts).

10.2. Recommendations

The commissioning of a risk question needs to be formalized and such RQ should be as limited as possible. They could also be narrowed to address a part of AW such as pain or frustration. RQ also needs to address the problem in not too divergent target populations.

In the further development of the AW RA methodology risk assessors taking part in such activities should interact in order to make the best use of experiences made so far.

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