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Review

A review of the criteria used to assess insensibility and death in hunted whales compared to other species

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Abstract

This review addresses the diagnosis of insensibility and death in various species so as to evaluate the validity of the current criteria used to judge death in hunted whales by the International Whaling Commission (IWC).

The only other species in which official criteria of death have been formulated is humans and these are controversial with the kernel of the debate being the definition of brain death. In slaughter animals, the moment of insensibility is regarded as the most important criterion and the issue has received scientific interest related to the pre-slaughter stunning. During hunting of terrestrial wildlife, the moment of death is usually regarded as the moment the animal falls and does not move.

Based on the data presented in the present paper, it is concluded that when death in whales is solely determined on the basis of the IWC criteria, which in practice are based on immobility, a significant proportion of animals will be recorded as being sensible and alive when they are actually unconscious and the time to death (TTD) will be overestimated. If the criteria are used in conjunction with a postmortem examination, the recorded TTD will be closer to the real TTD and can be used for comparison of methods and performance.

Keywords: Whales; Hunting; Animal welfare; Death criteria; Insensibility

1. Introduction

In the 1970s, whaling and, in particular, the killing methods were subjected to heavy criticism internationally and the issue was debated at many annual meetings of the International Whaling Commission (IWC) (IWC, 1977, 1978, 1979). In 1980, both existing techniques and alternative methods were discussed in an IWC workshop on the humane killing of whales (IWC, 1980). No final conclusions were drawn, except for a general agreement that further research was needed. The workshop also recognized that it was difficult to decide exactly the moment of death of a whale and therefore recommended the use of behavioural cues as indicators of death for comparison and evaluation of existing hunting techniques and for future research purposes.

The diagnostic criteria of death in whales, known as the "IWC criteria", were based on the advice from marine mammal experts and defined as "...the time taken for the mouth to slacken, the flipper to slacken and all movements to cease" (IWC, 1980). These signs, which could be applied by observers during whaling to estimate the time to death (TTD), were to be used in conjunction with pathological findings made during necropsy. The workshop decided that such behavioural observations should also be obtained from whales in controlled experiments in order to evaluate the criteria used to judge unconsciousness and death in the field. However, the validity of the criteria has been questioned and discussed in the IWC for more than two decades.

The only other species in which official criteria of death have been formulated is humans. This might be one of the reasons why the debate in the IWC has had a tendency to focus on how death is determined in human medicine (IWC, 1992a,b, 1995, 1997, 1999), rather than comparing the death of a whale with the death of other

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animals, and in particular other wildlife species that are hunted. However, the fact that much more data are available from humans and that whales have a very special status in the minds of many may explain why man has been referred to when whales are being discussed.

This review addresses for various species the medical criteria of death and the diagnosis of insensibility, including the theoretical basis and practical applicability, so as to compare and evaluate the validity of the current criteria used to judge insensibility and death in hunted whales. As the IWC criteria for whales have often been compared to the criteria for human beings, attention will therefore first be drawn to how death is determined and assessed in humans.

2. Criteria for death in humans

Public distrust of the medical profession's competence regarding the diagnosis of death goes far back in history (Arnold et al., 1968). In the 18th century it was argued that only putrefaction was a sure sign of death (Lamb, 1996). However, the criteria for human death have been refined and redefined following advances in medical technology. In the mid-19th century, the stethoscope was employed and public confidence grew as a more accurate detection of heartbeat and respiration was possible, and hence irreversible cessation of cardio-respiratory functions could be confirmed, i.e., diagnosis of systemic death (Lamb, 1996). This method is still the most widely used today and regarded as a legally recognized procedure to pronounce death. Medical circumstances may require the use of confirmatory tests, such as an electrocardiogram (ECG), but these are exceptions. The vast majority of the world's people die from what can be termed "natural causes" and without a physician present. In countries that demand a death certificate, the declaration of death may therefore take place a certain time after death has supervened.

Definition and determination of death in humans is obviously not only a medical issue as legal, philosophical, ethical, cultural and religious aspects and beliefs are also involved. These have been thoroughly reviewed by Lamb (1996). An important point, though, is that in many countries the medical profession has no inherent authority to define or determine death as this authority is left to the legal system (Lamb, 1996).

In 1959, a new concept of death, namely "brain death", emerged in France (Mollaret and Goulon, 1959). It took a decade before this condition achieved worldwide medical recognition following the publication of the report of the "Ad Hoc Committee of the Harvard Medical School to Examine the Definition of Brain Death" (Anon., 1968), known as the "Harvard criteria". However, it took two more decades before the diagnosis was legally recognized in many countries (Hansen et al., 1992; Lamb, 1996). To diagnose brain death, the Harvard criteria required the absence of all of the following: cerebral responsiveness, induced or spontaneous movement, spontaneous respiration, brainstem and deep tendon reflexes. It also recommended the presence of a flat electroencephalogram (EEG) and tests over a period of 24 h to reveal the persistence of the condition.

Such a prolonged period before death could be declared hampered the donation of viable organs for organ transplantation, and in 1977 the National Institute of Neurological Diseases and Stroke (NINDS) revised the Harvard criteria. The "NINDS criteria" demanded coma with cerebral unresponsitivity, apnoea, dilated fixed pupils, absent cephalic reflexes and electrocerebral silence, which should be present for 30 min at least six hours after the onset of the state (Anon., 1977). In the United States, the two concepts of death in humans, i.e., systemic death and brain death, were incorporated in the "Uniform Determination of Death Act" (Anon., 1981a), which stated that "an individual who has sustained either (1) irreversible cessation of circulatory and respiratory functions or (2) irreversible cessation of all functions of the entire brain, including the brain stem, is dead." Based on this Act, a panel of medical experts compiled the "Guidelines for the Determination of Death" (Anon., 1981b), which in principle is the formulation of diagnostic criteria (both cardiopulmonary and neurological) that physicians can use in determining whether death has occurred. These guidelines recommended that if clinical neurological examination and confirmatory EEG were carried out, brain death could be diagnosed after six hours, except in patients with drug intoxication, hypothermia, young age or shock. In the absence of confirmatory EEG, a period of at least 12 h was recommended. With respect to systemic death, the period of observation could under normal circumstances be restricted to a few minutes. However, the guidelines avoided defining time of death and stated: "The time of death recorded on a death certificate is at present a matter of local practice and is not covered in this document" (Anon., 1981b).

The primary mode of determining brain death in humans is, and presumably will continue to be, clinical neurological examination (Baumgartner and Gerstenbrand, 2002), but there are several recommended procedures to assist the diagnosis. The EEG is closely linked to brain death since it was the only available technical investigation able to explore brain function at the time when the Harvard criteria were formulated (Facco et al., 2002). It records the spontaneous electrical potentials generated by nerve cells in the cerebral cortex through electrodes placed on the scalp. If the electrodes are placed directly on the underlying cortex (electrocorticogram or ECoG), the recorded amplitude and potential signals are higher and faster (Fisch, 1991). In a state of unconsciousness, the EEG is never normal and three types of abnormalities may be distinguished: (1) distortion and disappearance of normal EEG pattern, (2) appearance and increase of abnormal patterns and (3) electrocerebral inactivity (ECI) or silence, popularly called iso-electric or "flat EEG" (Lopes da Silva, 1983; Anon., 1986).

The EEG is, however, not always a reliable indicator of death since it only monitors the activity in the cerebral cortex and not the brainstem function (Lamb, 1996). Severe brain damage to the cerebral hemispheres sparing the brainstem does not necessarily lead to death, and ECI has been recorded in comatose patients surviving cerebral anoxia, trauma and meningitis (Pallis and MacGillivray, 1980). Conversely, evidence of persistent electrocerebral activity does not exclude the diagnosis of brain death (Chatrian et al., 1996). Some patients who satisfy all clinical criteria for brain death and have no blood flow to their brains may demonstrate various degrees of EEG activity (Grigg et al., 1987).

As it became crucial to obtain viable organs for organ transplantations, measurements of evoked responses (ERs) were introduced as an ancillary procedure to the EEG. ER recordings are based on the electrical responses that auditory, somatosensory or visual stimuli produce in the brain of lesser amplitude in comparison to ongoing spontaneous EEG. They occur, however, at a fixed time after the stimulus has been applied and can therefore be extracted from the EEG by averaging multiple responses (Fisch, 1991). Measurements of brainstem ERs allow for the assessment of brainstem structures, but Firsching et al. (1992) reported that these are only relevant for the declaration of brain death in approximately 30% of cases. Cortical somatosensory and visual ERs have been found to be of more limited value for the diagnosis of brain death (Facco et al., 2002). Routine ER recordings are made with standard EEG disc electrodes, but the electrode placement and number depend on the sensory system under investigation (Fisch, 1991). To obtain adequate measurements, the bioelectric activity of about 100–200 stimuli have to be recorded for visual ERs and several thousands for brainstem auditory and somatosensory responses (Hall and Tucker, 1986; Fisch, 1991).

All methods of encephalography are extremely sensitive for recording artefacts, and several authors have emphasized their technical pitfalls and limitations (Egol and Guntupalli, 1983; Spudis et al., 1984; Hall and Tucker, 1986; Grigg et al., 1987; Fisch, 1991; Chatrian et al., 1996; Mäkelä et al., 1996). Numerous environmental and patient-related factors may compromise the validity of the recordings. Additionally, the EEG is less reliable in case of sedation and anaesthesia, hypothermia or presence of toxic or metabolic factors (Karasawa et al., 2001; Facco et al., 2002). Buchner and Schuchardt (1990) reported that inter- and intra-rater variability might account for diagnostic uncertainty in up to 20% when using the EEG. Despite these limits, all countries that have adopted the "whole brain death" definition recommend the use of EEG. According to Facco and co-authors (2002), this reflects the history of brain death, the traditional overestimation of EEG reliability and a need for objective confirmation of official valid and accepted criteria in light of the development of better diagnostic techniques.

Cerebral blood flow tests have been increasingly advocated as the most reliable method to diagnose brain death, since a loss of blood perfusion to the brain is incompatible with sustained brain viability. However, several of the procedures are invasive and might under some circumstances be deleterious to the critically ill patient (Lamb, 1996). Additionally, these tests are expensive and greatly depend on operator capability and skill (Facco et al., 2002).

Brain death is still a controversial issue and topic of passionate debate in the medical society (Troug and Fackler, 1992; Halevy and Brody, 1993; Powner et al., 1996; Youngner et al., 1999; Potts, 2001; Schlotzhauer and Liang, 2002; Wijdicks, 2002; Shemie et al., 2003). Taylor (1997) considers it a social construct primarily created for utilitarian purposes to permit organ transplantation. Others argue that the concept suffers by internal inconsistencies in both the test-criteria and the criterion–definition relationship (Karakatsanis and Tsanakas, 2002). The kernel of the debate is primarily the definition of *brain death*. In the UK, it is defined as the death of the brainstem, while US and Italy demand death of the whole brain (Facco et al., 2002). This discrepancy is reflected by differences in the diagnostic rules adopted by these countries: the EEG is mandatory in Italy, recommended in the US and irrelevant in the UK (Facco et al., 2002).

Reports on the presence of gross spontaneous movements and reflexes in brain-dead patients have additionally contributed to the dispute (Patterson and McShane, 1991; McNair and Meador, 1992; Urasaki et al., 1992; Schiff et al., 2002). Gerstenbrand et al. (1990) reported that 60% of brain-dead patients might exhibit medullospinal-initiated movements and reflexes for prolonged periods. Clinically brain-dead patients may additionally maintain hypothalamic endocrine function, cerebral electrical activity and even environmental responsiveness (Troug and Fackler, 1992; Schiff et al., 2002).

3. Domestic animals

Evaluation of death in domestic animals is normally encountered when pets are euthanased and livestock are slaughtered. The diagnosis is almost exclusively based on the cessation of the heart and respiratory activity, or that the animal has been exsanguinated, but no official criteria of death have been formulated. In a report on euthanasia by the American Veterinary Medical Association (AVMA), the issue is dealt with in a very generalized manner: "Death must be confirmed by examining the animal for cessation of vital signs, and consideration given to the animal species and methods of euthanasia when determining the criteria for confirming death" (AVMA Panel on Euthanasia, 2001).

The reason why the issue is treated in such general terms may be due to the fact that a veterinarian does not have to estimate the legal time of death of their patients in the same way as a physician or forensic medical doctor. Additionally, with respect to slaughter animals, the moment of death is less important than the moment of insensibility, i.e., when the animal no longer responses to painful stimuli. In many countries, the killing of slaughter animals therefore consists of a two-step process: stunning and bleeding. Blackmore and Delany (1988) defined technical death of slaughter animals as "irreversible insensibility due to cerebral anoxia, usually due to severance of both common carotid arteries or the vessels from which they arise", but during slaughter, TTD of each individual animal is not recorded.

EC Council Directive 93/119 (Anon., 1993) defines stunning as "Any process which, when applied to an animal, causes immediate loss of consciousness which lasts until death". This is the ideal, but in industrialized slaughter plants, the process is by no means devoid of methodological and technical faults and weaknesses. Millions of animals are slaughtered each day worldwide. In Norway alone, more than 43 million carcasses were approved for consumption in 2002 (Statistics Norway, 2003). In such a large industry there is little room for individual consideration for each animal, and both technology and regulations have been adapted to meet the requirement of a high-pace process.

In the early 1980s, the various aspects of the slaughter procedures, and primarily stunning methods, received much attention. This was due to an increased focus on the welfare of slaughter animals; a growing awareness on the deleterious effect on meat quality caused by poor techniques, and the constantly increasing efficiency demands in industrialized slaughter plants (Rose et al., 1991). In the report "Priorities in Animal Welfare Research and Development" (Anon., 1988), three major issues were set up for future research: (1) fundamental physiological work to establish signs to indicate that an animal is completely insensible and to what extent reflex actions and movement post-stunning indicate awareness to pain; (2) improved stunning methods and assessment of the effectiveness of various electrical stunning methods for inducing unconsciousness and avoiding recovery prior to death and (3) improved pre-slaughter handling.

The assessment of the state of unconsciousness and insensibility after stunning can theoretically be obtained either by observing behavioural signs (the presence of voluntary motor activity and the presence or absence of reflex reactions), by recording electroencephalographic activity or by postmortem investigations on the severity of trauma produced. To evaluate the effect of different stunning techniques, brain function has extensively been studied by means of electroencephalography in a variety of species including poultry (Gregory and Wotton, 1986, 1987, 1988, 1989, 1990a,b,c, 1991a,b; Raj et al., 1990, 1991, 1992a,b; Raj and Gregory, 1993; Lambooij et al., 1999; Mouchonière et al., 2000; Raj and O'Callaghan, 2001; Wotton and Sparrey, 2002), pigs (Wotton and Gregory, 1986; Gregory et al., 1987; Raj et al., 1997), cattle and sheep (Lambooy and Spanjaard, 1981; Newhook and Blackmore, 1982a,b; Gregory and Wotton, 1984; Devine et al., 1986; Daly and Whittington, 1986, 1989; Daly et al., 1986, 1988; Anil and McKinstry, 1991; Bager et al., 1992; Cook et al., 1995, 1996; Anil et al., 1995; Velarde et al., 2000; Wotton et al., 2000), rabbits (Anil et al., 1998, 2000; María et al., 2001) and fish (Kestin et al., 1991, 2002; Robb et al., 2000, 2002; Lambooij et al., 2002a,b; Robb and Roth, 2003). A brief summary of the principal results obtained in these studies will be given below.

When red meat animals are electrically stunned, seizure activity is produced. This is recognized by physical activity (tonic/clonic convulsions) and a great increase in the EEG magnitude and frequency, which are interpreted as incompatible with a coherent brain function based on anecdotal studies of human generalized seizures. The minimum current required to induce a seizure in the majority of animals, usually taken as 98% of individuals (Gregory, 1991), has been used as the recommended stunning current. In poultry, however, it has been reported that electrical stunning only produces low frequency polyspike activity in the brain, which is not necessary associated with unconsciousness (Gregory and Wotton, 1987; Gregory, 1991). Therefore, the recommendations for chickens have been to use the minimum current that prevents the brain from responding to an external applied stimulus (Gregory, 1991). Testing of ERs after electrical stunning have, however, not been applied to all species of poultry, and in some countries the legal standards for geese and ducks are based on the minimum current required to induce a cardiac arrest at stunning (Gregory, 1991).

Studies of captive bolt stunning have shown that if the bolt is placed correctly, shooting produces delta and theta waves tending to an iso-electric line on the EEG. It is assumed that the animal is unconscious by analogy to similar EEG changes described in man. However, to evaluate a mechanical stunning procedure using electroencephalograms may be difficult as the blow to the head may disturb the recordings or destroy the electrodes. Neuropathological studies of the captive bolt (Finnie, 1993, 2000; Finnie et al., 2002) have shown that based on the neurotrauma produced such stunning should immediately be followed by further action (sticking) to ensure that the animal is rendered permanently unconscious. The penetration of the bolt is not the primary cause for loss of consciousness. It is the energy that delivered to the animal's head that is most important. Incorrect positioning may fail to produce unconsciousness and shooting in the frontal position is the most effective and considered the only acceptable method for cattle, swine and horses.

In cattle, it has been shown that if the site of stunning is more than 4–6 cm from the ideal position, the stunning efficiency is reduced by 60% (Daly, 1987). Sheep and goats may also be shot from behind (in the poll position) if the presence of horns prevents stunning in front of the head. In such cases, the shot must be placed immediately behind the base of the horns and aimed towards the mouth. In an animal stunned by the captive bolt, the heart can carry on beating for many minutes, but proper stunning will eventually cause both breathing and heartbeat to stop (Gregory, 1991).

The only form of chemical "stunning" of slaughter animals in present use is carbon dioxide (CO_2), which is widely used on pigs. The animals are taken into a chamber filed with CO_2 and kept there for 45–60 s. The acceptability of this method on welfare grounds is still controversial, as electroencephalography has shown that the animals may have to endure a moderate to severe respiratory distress for a certain time period prior to the loss of brain responsiveness, which is not in complete accordance with a goal that stunning should cause immediate loss of consciousness.

As for humans, the data from animal electroencephalographic recordings have limitations and require some degree of subjective evaluation. They cannot establish definitely whether or not an animal is fully sensible or the definite time at which an animal becomes insensible (Blackmore and Delany, 1988), but results obtained in such studies with their defined confidence bands have served as guidelines to change stunning procedure requirements, especially related to the required current levels for electrical stunning and correct placement of the captive bolt. However, unanswered questions still exist and a major point is whether stunning actually renders the animal insensible (Manteca, 1998).

According to Grandin (1994), there is a tremendous need for veterinarians to increase their knowledge of physical methods of euthanasia and humane slaughter, as there seems to be a lack of such practical and scientific knowledge. It is obvious that in a large and industrialized slaughter plant, where hundreds or thousands of animals are slaughtered each day, it will never be possible to accomplish a sophisticated monitoring system to measure brain activity in individual animals. This is only possible during the experimental phase. In practice, the effect of stunning has to be judged by more simple methods.

The traditional reflexes used to judge the depth of chemical anaesthesia are according to Blackmore and Delany (1988) of little relevance to the slaughter process, except for CO_2 anaesthesia. When an animal is stunned by a physical method, absence of spinal reflexes is not an indication of insensibility. Convulsions are rather regarded as a reliable indication that the animal has been properly stunned (Blackmore and Delany, 1988; Gregory, 1991). Pedal reflexes have been observed for more than two and five minutes after electrical stunning in sheep and cattle, respectively (Blackmore and Newhook, 1982), and it may be intensified if the animal is handled, which can cause problems in terms of carcass restraint and worker safety (Blackmore and Delany, 1988). Palpebral reflexes, which are not under cortical control, may be present in an electrically stunned animal and have been recorded in sheep and cattle for up to 200 and 400 s after exsanguination, respectively. In the case of ineffective electrical stunning, the reflex can be inhibited while the cerebral cortex is still functional and the animal may be sensible (Blackmore and Delany, 1988).

The presence of a corneal reflex indicates physiological brain stem activity and not cortical function and, consequently, it does not accurately distinguish between consciousness and unconsciousness (Anil, 1991). A corneal reflex has been evoked in calves for up to 44 s after the EEG has become iso-electric (Blackmore and Delany, 1988). Anil and McKinstry (1991) reported that as corneal reflexes were recorded although there were no concomitant visual or somatosensory ERs, brain stem reflexes should not be relied on as indices of recovery in electrically stunned sheep.

In animals stunned by percussive methods, there is no correlation between the extent of cranial damage and the loss of corneal reflexes (Blackmore and Delany, 1988). Also, the pupillary reflex has been considered to be of little value after slaughter, because the process interferes with the blood supply to the retina (Blackman et al., 1986).

Registration of respiration or rhythmic breathing is widely used as a criterion to judge the effect of both percussive and electrical stunning in slaughter plants (Blackmore and Delany, 1988; Gregory, 1991; Grandin, 1994). However, as with the corneal reflex, the cessation of respiration does not correlate with the extent of cranial damage produced by percussive stunning methods (Blackmore and Delany, 1988). It normally ceases during the tonic phase of a physical stunning process, but usually returns as periodic respiratory gaps, which have been recorded in cattle and sheep for up to six minutes after stunning (Blackmore and Delany, 1988). Wotton and Sparrey (2002) reported that identification of rhythmic breathing movements in ostrich after stunning was difficult because spinal reflexes produced contraction of limb muscles, which resulted in almost rhythmic body movements that easily could be confused with breathing movements.

Walking movements are usually considered as a sign of sensibility, but this is not an absolute criterion. It may be seen even when the head has been separated from the body ('the running headless chicken'), and muscular contractions and spasms are common long after animals have been bled and died. María et al. (2001) observed that electrically stunned rabbits regained posture without responding to nose prick, indicating that they could still be in an unconscious state.

There are, however, certain clinical parameters that are associated with effective stunning, which can be used for surveillance of individual animals or periodic control. The signs of effective CO_2 narcosis are those associated with deep surgical anaesthesia, such as loss of withdrawal and palpebral reflexes (AVMA Panel on Euthanasia, 2001).

According to Gregory (1991), there are two approaches to assess the effectiveness of electrical stunning. First, and most important, is to test the efficiency of the equipment. This includes regular control of the magnitude of the current applied (using ammeter and voltmeter), the positioning of the electrodes and the duration of stunning. The second approach is to evaluate the animal's physical behaviour, in which the only criterion for unconsciousness is the seizure. This means that the successfully stunned animal should go rigid (tonic). In red meat animals, the hind legs are flexed under the body, the forelegs initially become stiff, but may straighten out, the eyes become fixed, the head bends backwards and respirations should stop. After 15–20 s, a clonic (kicking) phase sets in and the animal should gradually relax and make walking movements with its legs. Bleeding should take place before the clonic phase sets in. When poultry are stunned with electricity, the neck will be arched, the head directed vertically and rapid body tremors will usually appear in the tonic phase. Additionally, the eyes will be open, the wings held close to the body and the legs will be rigidly extended.

In electrically stunned animals and birds, it is considered pointless to assess reflexes during the tonic and clonic phases as the animal is convulsing and no meaningful measures will be obtained (Gregory, 1991). However, it is not uncommon that slaughterhouse inspectors assess electrical stunning using the corneal reflex (Gregory, 1998), but Grandin (2001) has suggested that observation of spontaneous natural eye blinking without directly touching the eye is a better measure under field conditions.

Indicators of unconsciousness following use of a captive bolt are that the animal should immediately collapse to the floor with its hind legs flexed into the body. It may also draw in its forelegs, but they straighten after a short period of time (Blackmore and Delany, 1988). The animal must not show normal rhythmic breathing. The muscles of the body are contracted and the back is usually arched and kicking may be seen after the initial muscle contraction phase. Good stunning produces relaxation of the jaw and consequently the tongue will hang out when the animal is hoisted (Gregory, 1991). The head should be completely relaxed, the ears should drop and the eyeballs have a fixed position. If the ears or head respond to being poked with an electrical pod, the animal may be conscious (Grandin, 1980). It is often impossible for the captive bolt operator to test eye reflexes routinely because the animals fall down and are convulsing.

As the testing of insensibility in stunned animals using indirect effects, such as behavioural signs and reflexes, is a challenge in practice, much effort in industrialized slaughter plants is put into inspection and control of the stunning gears and operator routines. However, considerable problems still exist in many slaughter plants. Grandin (1998) reported that of 11 federally inspected beef plants in the US, only four were able to render 95% of the cattle insensible with a single shot. In a study from the 1990s, it was reported that 94% of the cattle were stunned instantaneously in UK abattoirs, while the equivalent number for pigs were 80% (Daly and Whittington, 1992; Anil and McKinstry, 1993). However, it was found that as many as 53% of young bulls had to be re-shot twice or more before they were declared unconscious (Kestin, 1992; Daly and Whittington, 1992),

4. Hunting of terrestrial wildlife

According to US Fish and Wildlife Service (Anon., 2001b), 13 million people enjoyed hunting a variety of species within the United States in 2001. An estimated 230,000 people in Great Britain participate in hunting, and the annual cull of deer in the UK is around 250,000 animals (Anon., 2000). In 2001 in Norway, about 200,000 hunters felled 65,000 big game and more than 800,000 small game (Statistics Norway, 2002). There is abundance of popular literature, tutorial books and reference work on hunting, hunting histories, wildlife management and outdoor life. However, disregarding whaling, surprisingly little scientific data exist regarding studies of the efficiency of different methods and weapons in use, including evaluation of moment of insensibility and TTD as well as other animal welfare concerns in connection with hunting.

In the beginning of the 1960s, data were collected on rifle projectile performance in moose hunted in Norway and Sweden. The Swedish material was collected during meat inspection and included 214 animals. It was estimated that about 65% of the shot wounds were in regions of the body where the injury had probably caused a rapid death (Hässler, 1963). The Norwegian data were collected by hunters marking the hit zone on an illustration chart of the animal (1535 animals) and during meat inspection (138 animals) (Paus, 1965). Shots to the chest and neck region causing injury considered to have resulted in rapid death were found in 68% and 57% of the animals, respectively. However, Øen (1995a) reported preliminary results from moose hunting, indicating that only 21% lost consciousness and died instantaneously or very rapidly. The material compromised 105 moose hunted in the period 1975–1994. TTD in this study was based on postmortem investigation, testing of the corneal reflex and behavioural observations. If the animal fell out of the hunter's sight, TTD was estimated according to the distance the animal had covered before collapsing.

There are also some studies available on hunting efficiency and animal welfare consideration for hunting with dogs or kill-traps of typical small predators such as lynx, foxes, raccoons and marten-like animals (Proulx et al., 1990, 1993, 1995; Proulx and Barrett, 1993a,b; Proulx and Drescher, 1994; Pohlmeyer et al., 1995; Warburton et al., 2000; White et al., 2003) as well as evaluation of welfare implications of shooting ducks, impala and red deer (Cochrane, 1976; Nicklaus, 1976; Lewis et al., 1997; Bradshaw and Bateson, 2000). However, for a majority of hunted species, no scientific studies related to insensibility and TTD seem to be available.

The techniques suitable for killing domestic animals are seldom applicable to wild animals or to animals that are unaccustomed in being enclosed or handled by people. The most widely used weapon to hunt animals is a gun, and the animals are normally shot at a certain range and are therefore not in the immediately reach of the hunter. The diagnosis of death is therefore often based on a combination of an evaluation of the hit point and whether this is likely to have caused fatal damage, which according to good shooting practice when shooting with a rifle is the chest (Gjems et al., 2003), and observation of the animal's behaviour.

To approach a potentially conscious wounded wild animal to check the pulse, respiration or reflexes might sometimes be hazardous and even dangerous. Total immobility is therefore used as an indicator of death. "The animal fell on the spot" is a common expression among hunters when describing a well-placed shot. It is, however, not unusual that an animal will move a certain distance, even when the projectile fatally damages vital organs and insensibility rapidly commences. If the animals falls down, but still moves (coordinated or not) good hunting practice implies that the hunter slowly and carefully approaches the animal and fires a second round directed towards the brain, i.e., the *coup de grace* (Gjems et al., 2003). Responsible hunters will never hesitate to re-shoot an animal if doubt exists whether it is still conscious and alive. Some hunters actually use this procedure as a matter of routine on all animals, even if no movements or signs of life are registered.

Hunting with rifle or shotguns involves an inevitable risk of only wounding the animal, as the projectiles are fired from a distance and the animals often present a moving target. The area of impact of the first round will always be decisive with regard to how quickly the animal collapses and dies. Even though it is often possible to fire a rapid volley of shots the risk of missing the vital areas will be greater as the animal will probably start running and there is no time to aim properly (Øen, 1995a). If a wounded animal escapes the first hit, all reasonable attempts should be made to locate it in a proper manner.

In the big game hunts in Norway, as well in other Scandinavian countries, it is mandatory that a tracking dog is available (Gjems et al., 2003). When retrieving wounded big game, it is a common and recognised practice not to start searching for or pursue the animal until about an hour after it has been shot to give the animal time to calm down and become weaker from loss of blood and impaired function (Gjems et al., 2003). Such a practice may perhaps appear repulsive, but it is employed to preclude the animal running a great distance because it is disturbed and scared again shortly after being wounded. Under such circumstances, the TTD can only be estimated in the field based on the degree of damage inflicted by the wound and the distance the animal has covered before collapsing.

5. Criteria of insensibility and death in whales

Annually, Norwegian fishermen harvest about 500–700 minke whales (*Balaenoptera acutorostrata*) from the Northeast Atlantic stock, which consists of more than 107,000 individuals (IWC, 2003a). Worldwide, less than 1500 whales are hunted of the cetacean species that are under management of the IWC (IWC, 2003a).

Since 1981, Norway has been acting as a driving force in the efforts to improve the hunting techniques for whales when a research program was initiated to find better methods for killing minke whales. A systematic collection of data on the hunting method used at that time (the cold harpoon) was carried out by Øen (1983a, 1995a,b) and, on request from the IWC, field experiments with high-velocity projectiles were performed (Øen, 1995c). Simultaneously, other possible alternatives were reviewed such as the use of electrical harpoons (Øen, 1983b), drugs (Øen, 1984), compressed air, modified cold harpoons and explosives (Øen, 1995a). The principal result of the program was the development of a new harpoon grenade with the detonating explosive penthrite (Øen, 1995a,d). Data on survival times from the Norwegian whale hunt in 1984–1986 showed that a substantially higher percentage of instantaneous deaths were recorded for penthrite grenades (45%) than for cold harpoons (17%) (Øen, 1995d), and consequently, the cold harpoon was banned in the Norwegian hunt.

The validity of the IWC criteria of death in whales that were defined in 1980 (IWC, 1980) was already discussed in 1984 in the Humane Killing Group of the IWC (IWC, 1984). At that meeting the group recommended that as a practical field measurement, cessation of movement could be used as the criterion for death and that this should be determined by direct observation of the whale at the surface.

The research data on TTD that were collected by official inspectors (mostly veterinarians) on board every Norwegian whaling boat from the early 1980s up to 2002 have been based on registration of the time (using a stop-watch) from the impact of the harpoon until the whale fulfilled the IWC criteria. Additionally, the inspectors collected information on harpoon and grenade performance and registered whether vital organs like the heart, lungs, major vessels or the CNS were damaged. However, as the Norwegian whaleboats are small fishing vessels (average length about 22 m), a thorough necropsy was difficult to carry out during regular hunting (Øen, 1995a). Registrations of damage to organs made by the inspectors had therefore to be limited to a simple yes/no answer to whether severe gross damage could observed. There was no opportunity or time for the official inspectors, whose primary task was to observe that the hunt was carried out in accordance with the legislation and collect numerous other biological and ecological data important for the management of the hunt, to do extensive postmortem examinations. Hence, immobility was the mostly used criterion in practice in the Norwegian investigations and reports on TTD, i.e., any whale that moved or breathed had to be registered as being alive until all movements ceased unless the inspectors were able to register postmortem findings that clearly indicated that the animal died prior to this (Øen, 1995a, 1998, 1999, 2000, 2001, 2002).

Norwegian research also contributed to the development of a penthrite grenade for the Alaskan Eskimos' hunt for bowhead whales (*Balaena mysticetus*) during a joint research program that started in 1987 leading to markedly shortened survival times and reduced losses compared to traditional methods (IWC, 1990, 1991, 1993, 1994; Øen, 1995a,e; O'Hara et al., 1999). The first hunting trials on bowhead whales in 1988 were conducted with crews appointed by the Alaskan Eskimo Whaling Commission and in areas where scientific personnel could perform postmortem inspections on landed whales (Øen, 1995e). In the following years, the hunters were responsible for the data collection and used the IWC criteria to establish the TTD. However, in such hunts it is dangerous for hunters to remain close to the whale following the strike and the crew must monitor the whale from a distance for at least 5–10 min and then gradually approach and secure the whale to prepare it for towing once it is confirmed dead (Government of USA, 2003). Thus, the ability to immediately assess death is limited and consequently TTD may be overestimated.

When a minke whale is hit in vital areas by a penthrite grenade as it rises to the surface to blow it may stop swimming immediately, roll on to its back, float for a short time before sinking with slackened jaw and the flipper along side the body (Øen, 1995a). A whale that is shot in or near the brain with the rifle will also normally turn over immediately and the flippers and jaw will relax. If the whale does not die or lose consciousness rapidly, it maintains its normal position in the water and swims actively, dives and resurfaces to blow (Øen, 1995a). However, a significant problem, both in the Norwegian and Alaskan hunt, besides the safety hazards and practical difficulties in performing a postmortem examination, has been that when an animal is shot in vital areas as it dives after blowing or sinks after the impact confirmation of death based on behavioural signs cannot perform until the whale is along side the boat, which may take several minutes (Øen, 1995a,e).

Due to uncertainty concerning the size of the Northeast Atlantic minke whale stock, the Norwegian authorities introduced a temporary ban of the catch of this species in 1987. However, as sighting surveys conducted in the following years (1988–1990) indicated that the stock was large enough to allow it to be harvested (Haug et al., 1998), the issue of killing methods was again raised at the IWC annual meeting in Reykjavik in 1991 (IWC, 1991). At that meeting it was decided that a new workshop on killing methods should be held in conjunction with the IWC annual meeting in Glasgow in 1992. This workshop recommended that research should be undertaken to investigate the basis of agreed criteria for assessment of loss of sensibility and TTD in whales under controlled conditions to establish baselines. Further, it recommended that postmortem examinations should be performed to determine location and extent of injuries after detonation of penthrite (IWC, 1992a,b).

As a part of an extensive marine mammal research program in Norway in the 1990s, the hunting equipment for minke whales was further modified and the hunting procedures were changed (Øen, 1995a). The hunters were obliged to attend annual training courses and pass shooting tests for both harpoon gun and rifle prior to the hunt. In 1994, 59% of the minke whales were recorded as instantaneously dead according to the IWC criteria (Øen, 1995a,d). One of the changes in the hunting procedure was a recommendation that all whales should be hauled in to the boat immediately for control and, if necessary, re-shooting. When the animal was hauled rapidly in this way, movements of the mandibles, flippers and tail generated by water currents could be interpreted as signs of life (Øen, 1995a).

A pilot study conducted during the scientific whaling in 1992 and 1993 and during the traditional hunt in 1993, which included gross and histological examination of brains from hunted minke whales, showed that movements of both flippers and tail occurred in animals that were dead (Øen, 1995a; Øen and Mørk, 1999).

At the IWC annual meeting in 1994 in Mexico, Øen (1994) reported that TTD from minke whales could have incorporated biases due to the fact that the criteria did not allow for unconscious uncoordinated movements triggered by reflexes and due to delayed assessment of death in animals which sank before death could be confirmed. At the IWC meeting in Dublin the following year, the Workshop on Whale Killing Methods agreed: "The IWC criteria used to indicate death in whales are incomplete and under some circumstances may be misleading" (IWC, 1995). A working group of scientists was set up by the workshop, which identified two key research needs: (1) examination of trauma, and its consequences, caused by harpoons and other devices used to capture whales and its relationship to the reactions in captured whale and (2) the determination of better criteria for determining the time of onset of permanent insensibility in whales (IWC, 1995).

The applicability of advanced methods for assessment of unconsciousness and death normally used under controlled conditions in humans and in experimental animal studies was evaluated for use on whales in 1992 (IWC, 1992a,b). Already at that time it was recognized that these measures would be very difficult, in fact impossible, to apply during regular hunting due to lack of technical facilities and other practical limitations. This has not prevented, however, numerous proposals of this nature appearing again and again in the IWC and other forums, even though many scientists have had significant concerns about the validity of such data collection (IWC, 1992a,b, 1995, 1999, 2003b).

Several countries, and in particular the UK, New Zealand and Netherlands, have for many years advocated that a substantial amount of data on the killing of whales should be included in a permanent observation or inspection regime (IWC, 1995, 1998, 2001, 2003b). Madie (1997) proposed that heat-sensitive camera equipment should be used on hunted whales to evaluate the cessation of blood circulation, as well as hydrophones to record vocalization and evaluation of pupillary dilation by observation through binoculars. Lambooij and van Liere (1999) suggested that scientists should observe the process of dying of a whale in detail and monitor behaviour (including breathing frequency), somatosensory responses (including tongue and anus), ocular responses, electrical brain activity and brainstem responses after the first impact of the killing method until the animal was considered to be in the vegetative state. These authors considered that the procedure would be applicable for aboriginal subsistence whaling and for euthanasia in beached whales. The Royal Society for the Prevention of Cruelty to Animals (RSPCA) has proposed a basic protocol for data collection in relation to whaling operations. According to the RSPCA (Anon., 2001c), the aim of the protocol was to encourage whalers to measure a total of 34 parameters that could be used to validate indices of sensibility, either from the deck of the ship, by using an inflatable boat or by a diver in the water, and then validate these indices with the use of EEG or ERs recordings.

When the IWC rejected electroencephalography as a mean to assess unconsciousness and death during regular whaling in 1992 (IWC, 1992a,b), it did, however, suggest that such recordings should be performed from cetaceans either in controlled experiments or in countries were whales commonly strand like Australia or New Zealand to establish baselines. However, such studies have not yet been conducted. The reason might be that it is difficult to get acceptance to do invasive or lethal experiments on cetaceans. However, EEG and ERs have been recorded in captive dolphins and other small toothed whales to elucidate sleep pattern and hearing (Popov and Supin, 1990, 1997, 1998, 2001; Popov et al., 1998, 2001; Mohl et al., 1999; Szymanski et al., 1999; Lyamin et al., 2002a,b; Ridgway, 2002).

In 1997, a research project was initiated in Norway and a new and improved penthrite grenade, the "Whalegrenade-99", was designed and constructed. The grenade was implemented from the 2000-hunting season, and since then about 80% of the animals have been recorded as instantaneously dead based on the IWC criteria (Øen, 2001, 2002, 2003). The grenade has later been implemented in the Greenlandic hunt for minke whales and in a modified form for fin whales (*Balaenoptera physalus*) in the Icelandic scientific hunt for minke whales and for research purposes in the Japanese scientific hunt of minke whales. Simultaneously, a research program was initiated to find more precise cause of death in hunted minke whales. The study focused especially on the role of cerebral damage caused by detonation of penthrite as well as the brain-damaging effect of the heavy calibre rifles used as backup weapons in the Norwegian hunt, to elucidate whether brain lesions of sufficient severity incompatible with sensibility were produced. Similar studies have been conducted in slaughter animals (see previous section) and substantial comparative knowledge is also available from experimental animals and humans, both on blast-induced neurotrauma (for review see, e.g., Knudsen and Øen, 2003) and craniocerebral missile injury (Demann and Leisman, 1990; Abdolvahabi et al., 2001; Hardman and Manoukian, 2002).

The results obtained from minke whales showed that the weapons in current use in Norway are highly capable of causing permanent brain damage of sufficient severity to account for an instantaneous or rapid loss of consciousness. Depending on where the penthrite grenade detonates it may cause shock wave-induced acute traumatic brain injury (TBI) in addition to the direct damage it inflicts on other organs or organ systems (Knudsen and Øen, 2003). Based on the organ damage produced, including TBI, it was concluded that if the grenade detonated in an area ranging from the mid-thorax and forward to the skull, near 100% of the whales lost sensibility immediately or very rapidly. However, severe TBI was also registered when the grenade detonated at the interface between thorax and abdomen (Knudsen and Øen, 2003). Further, the study revealed that one round with the currently used rifle calibres and ammunition in the Norwegian hunt is highly efficient in causing permanent and very severe brain damage when it hits in or near the brain or in the upper cervical spine (Øen and Knudsen, 2003).

Table 1 sums up the behavioural observations that were recorded from the 35 animals in which pathological examination confirmed that the penthrite grenade detonation had caused acute TBI in addition to fatal damage to several other vital organs in most cases (Knudsen and Øen, 2003). As appears from the table, the complete fulfillment of the IWC criteria could only be confirmed in seven of the 35 animals at the moment of impact of the grenade. In six whales, the jaw remained closed as the animals turned completely on their back so that gravity prevented it from slackening. In two, the flippers were partly erected as the animal sank and in four animals the tail shivered for some time (10–30 s) after the detonation. Seven whales showed behaviour that looked very much like tonic/clonic seizures lasting for 20–30 s up to several minutes. The back was arched and the head was directed backwards (ophisthotonus) and some also thrashed their tails violently. The flippers could be relaxed or partly erected. As with slaughter animals (Blackmore and Delany, 1988) and seals (Blix et al., 1970), spinal reflexes probably trigger these convulsions after the motor control of the spinal cord has been lost due to damage of the higher controlling centres in the brain. Nine animals disappeared out of site immediately after the detonation and the IWC criteria could not be confirmed until they were at the boat side after some minutes (1–5).

Table 1
Summary of behavioural observations in 35 minke whales with acute traumatic brain injury inflicted by the detonation of penthrite

Animal behaviour	No. of whales	%
Fulfilled IWC criteria at the moment of impact	7	20
No movement and relaxed flippers, but closed jaw (animal on its back)	6	17
No movement, slacken jaw, but flippers erected	2	6
Tail shivering, with or without relaxed flippers and jaw	4	11
Convulsions (ophisthotonus and/or tail trashing)	7	20
Not able to verify the criteria until the whale was at the boat side	9	26
Total	35	100

It is difficult to exactly know how many of the animals that did not fulfil all the IWC criteria at the moment of impact (Table 1) that would have been judged as instantaneously dead or unconscious by an inspector or observer. The eight animals that were motionless, but either had their jaw closed as they were laying on the back or held their flippers out in an angle a short period after the detonation, would most likely have been regarded as instantaneously dead, especially since several other vital organs like the heart, lungs or major vessels were seriously damaged in a majority of the animals in addition to the demonstrable TBI. With respect to the nine animals that went out of sight after being hit, the postmortem would give the inspectors an indication on how quickly they died. As a thorough postmortem may be difficult to conduct during regular hunt, and routine examination of the brain is impossible, it is more than likely that some of these whales would have been judged to being alive for several minutes. Earlier reports (Øen, 1995a) and the results obtained by Knudsen and Øen (2003) give strong evidence that this would also had been the case for animals that showed movement in their tails or were convulsing. Hence, the TTD for several animals would have been overestimated. This is concurrent with the results reported by Lambertsen and Moore (1983) who did a study on 19 fin whales and compared the time to cessation of active movement or jaw relaxation with estimates of the time to onset of terminal insensibility, by correlating behavioural records and postmortem findings. They judged that cessation of movement produces a consistent, but variable, overestimate of TTD.

6. Discussion and conclusions

Official criteria of death only exist for human beings and whales. The criteria of human death are still controversial and no uniform consensus exists in the medical community as to whether the established criteria are scientifically valid and unimpeachable. However, most people die from natural causes without a physician present but in countries that demand a death certificate, diagnosis of death is usually made using simple means and often after a certain time period after death has supervened.

In recent decades, medical progress and law changes have opened some new possibilities for defining and diagnosing death in human beings. The introduction and acceptance of the clinical state ''brain death'' has led physicians now to pronounce death in an artificially ventilated body that looks alive, i.e., the heart still beats and most of the organs besides the brain function normally. However, as the advanced and invasive procedures used to assist the diagnosis are only applicable in large hospitals and the availability for specialists varies – in low-income countries there is less than one neurologist per 3,000,000 citizens (Baumgartner and Gerstenbrand, 2002) – physicians generally have to use more simple criteria and diagnostic tools to diagnose death.

In food animals, the efficiency demands and very high pace during industrialized slaughter do not allow for the use of advanced monitoring systems like electroencephalography to evaluate insensibility and death in practice. This is only possible in experiments. Hence, official controls are to a large extent directed towards periodic inspections of the equipment in use, how it is applied, and the operator's skill and maintenance routines. Control of individual animals, including stunning efficiency, is mainly left to the operator.

In some countries, slaughtermen have to undergo training programs to obtain a licence for the right to slaughter animals (Anon., 1995, 1996b). In the Norwegian minke whale hunt, similar control procedures as in slaughter houses are applied, as authorized personnel control all hunting equipment and the hunters attend annual training courses and must pass practical shooting tests with both harpoon gun and rifle prior to each whaling season. Such demands and regulations have also been in force for seal and terrestrial wildlife hunters for decades in Norway.

However, the legislative demands concerning terrestrial wildlife seem to vary considerably between different countries, despite the fact that hunting is a widespread practice. The UK, for instance, did not implement the welfare of wildlife in their legislation until 1996 when ''The Wild Mammals (Protection) Act'' was introduced (Anon., 1996a). Recently, the ''Hunting Bill'' was passed in the House of Commons (Anon., 2002). With respect to animal welfare, the only demand included was that in the course of hunting reasonable steps should be taken to ensure that any wild mammal injured or captured is killed quickly and humanely and shot by a competent person. However, the Bill does not define how a person is regarded 'competent', does not specify any minimum demands for weapons to be used on different species, nor is there any demand for the training of hunters or for shooting tests to be required prior to the hunt.

When the criteria of death in whales were formulated in 1980, the initial intention was to find a standard ruling for researchers or observers to be able to compare the efficiency of different hunting procedures as well as evaluation of new methods. Although achievable as a simple way to measure TTD in the field, it soon became evident that the results obtained under regular whaling based on the IWC criteria could not give exact answers to when a whale became insensible or died and calls were made for supplementary investigations, including examination of trauma and its consequences as well as experimental studies (IWC, 1992a,b, 1995).

Some of the proposals for data collection that have been put forward in the IWC and other forums would have been questionable with respect to personnel safety and animal welfare if they were to be applied during the regular hunt. Anyone who is familiar with fieldwork and field-based research will appreciate the difficulties in applying sophisticated technical equipment, such as EEG, during adverse circumstances. An extra complicating factor in whale hunting is that the animal is in the water.

In most countries, including Canada, Greenland, Iceland, Norway, Russia and US, whale hunting is carried out from small skin or fishing boats in Polar waters. The animals are large and cannot be restrained or handled before they are dead. The minke whale may weigh up to 10 tons (Jonsgård, 1992), while the bowhead whale may achieve a weight of more than 140 tons (George et al., 1990). Testing of reflexes or other physiological parameters on these large animals in such cold water, which has been proposed repeatedly (Madie, 1997; Lambooij and van Liere, 1999; Anon., 2001c), could potentially put people's lives in danger. For example, in aboriginal subsistence whaling of the bowhead or grey whale (*Eschrichtius robustus*), it would be extremely dangerous for the hunters to come close to a whale that might not be motionless and dead (Government of USA, 2003; Russian Federation, 2003). Nevertheless there have been participants in the IWC who have argued that safety of the hunters is of secondary importance to the welfare of the whales (IWC, 1992a,b). Such arguments are not in accordance with, for instance, industrialized slaughter where the safety of the personnel is given high priority (Blackmore and Delany, 1988). Neither is it in accordance with the considerations that are given to those who work with or observe euthanasia of beached whales in countries where such incidents are common.

In several countries, including New Zealand and the US, public opinion and press media considerations as well as personnel emotional and safety concerns are given just as high priority as animal welfare considerations when choosing killing method (Hyman, 2001; IWC, 2003b). However, in the author's point of view the attention and focus of the operator should be that the animal is killed as swiftly as possible. During whaling, as in all other activities where animals are killed, this implies that if any doubt exists whether the animal is still conscious or alive the hunter must re-apply the killing method. Data collection cannot in any way delay or hamper this. As in slaughter animals, a sharp distinction therefore has to be set between experimental research on one side and routine or periodical controls on the other side.

Concerns have been raised as to whether the IWC criteria, which in practice centre on immobility, ignore the risk that the whale is only paralysed, but still conscious (Blackmore, 1992; Kestin, 1995; Anon., 2001c). If a whale is rendered totally immobile with paralysed flippers and tail, equivalent to quadriplegia in terrestrial mammals, the damage to the spine must occur in the mid or upper cervical cord (Santiago and Corbett, 2002). The results obtained by Knudsen and Øen (2003) showed that detonation in this area simultaneously causes massive brain damage and hence it is not likely that the animal remains consciousness. The study also revealed that detonation in the spine as far back as in T7 will induce severe acute TBI with gross evident haemorrhages (Knudsen and Øen, 2003). Additionally, an upper cervical lesion at the level of C3–C5 (damage to the phrenic nerve) will be fatal due to respiratory arrest following paralysis of the diaphragm (Santiago and Corbett, 2002).

In previous times when only the cold harpoon was used, such paralysis may have occurred, as the velocity of the harpoon was so low that it would only cause direct damage to the cord (transection), but probably not concomitant brain damage. In the study on blast-induced neurotrauma in minke whales, none of the whales was hit in the spinal cord below T8 and we therefore do not know whether or not TBI will occur after detonation in the back part of the spine (Knudsen and Øen, 2003). It is possible that detonation in the lower part of the spinal cord in the lower thoracic or lumbar region could cause paralysis of the tail, equivalent to paraplegia in the lower extremities of terrestrial mammals, but then the whale would still be able to breath and move the flippers and show other signs of life and hence the IWC criteria would not be fulfilled.

Some have argued that marine mammals with their adaptation to a marine environment are capable of maintaining brain function and sensibility even under prolonged hypoxia and that this may influence the interpretation of insensibility and death of hunted whales (IWC, 1992a,b, 1995, 1999). Scientific evidence for profound differences in physiology associated with diving adaptations exists, including the fact that the CNS of marine mammals is protected by cardiovascular adaptations to maintain oxygenated blood supplies under extreme conditions (Blix and Folkow, 1983; Blix, 1987; Buttler and Jones, 1997), but there is no available scientific evidence that the CNS of whales and other marine mammals shows much difference physiologically compared to terrestrial animals. Neither is there any proof that the brain of marine mammals maintains its function after the circulation is collapsed, which normally will be the case when a penthrite grenade detonates intra-bodily.

It is, however, well known and also documented (Blix et al., 1970; Blix and Øritsland, 1970; Anon., 1990) that the increased storage capacity of oxygen in blood and musculature and the ability of anaerobic metabolism contribute to that muscular movements and reflex activity can persist longer in marine mammals than in terrestrial animals. In seals, it has been reported that after the brain has been totally destroyed, reflex activity mimicking voluntary movements, including withdrawal of the head, back arching and jaw gaping, may be observed for a long time (Søgnen, 1968). Blix and Øritsland (1970) recorded EEG and ECG in young hooded seals (*Cystophora cristata*) after a blow to the head with a "blow hook" and after exsanguination. The blow produced immediate electrocerebral inactivity and halt in somatic reflexes, but heart activity was recorded up to 45 min after exsanguination. The same procedure was applied on a domestic calf, in which heart activity was recorded only for 10 min. The longer persistency for heart activity in the seals was attributed to diving adaptations.

In whale hunting, as in other activities like sealing or slaughtering of domestic animals, it is of minor or no significance from an animal welfare point of view that some animals move after insensibility or death has supervened. The whale hunter will normally re-shoot any animal that shows movements or behaves in a way that gives any doubt whether it is still alive. Many hunters actually do this as a matter of routine and safety on every whale that is not floating on its back when the line is slackened (Øen, 1995a). In Russian aboriginal subsistence whaling, it has been reported that the hunters may overestimate the TTD because they consider death to have occurred when they are absolutely sure that the whale is not moving. Consequently, they also tend to overuse bullets to make sure that the whale is dead (Russian Federation, 2003). This is very similar to hunters of terrestrial mammals that fire another round if the animal moves the limbs, ears or eyelids when the hunter comes up to the felled animal or as a matter of routine. Also, knackers in slaughterhouses will not hesitate to re-stun the animal if there is any doubt that the first stunning attempt has failed.

In whaling, like in other forms of hunting or at slaughtering of livestock, an obvious interest in animal welfare as well as the need for personnel safety and efficiency, means that there is a requirement to ensure that the animals are killed as quickly as possible. Moreover, in whaling, a rapid death of the animal is imperative for securing of the prey. If whales are wounded and not dead, there is a considerable risk for losses and whale hunters will not hesitate to re-shoot any animal that survives the first killing attempt as soon as it comes within range of rifle or harpoon gun.

From a scientific point of view, the IWC criteria are, however, not fully adequate. Data collected during regular whale hunts based solely on these criteria will lead to an overestimation of the TTD, especially when the whales are shot when diving after the blow, or when it is dangerous for the hunters to approach the animal for some time after the strike. Based on current and comparative knowledge of criteria for insensibility and death in different species, it may be concluded that when death in whales is solely determined on the basis of the IWC criteria, a significant proportion of animals will be recorded as being sensible or alive when they actually are unconscious or dead. If the IWC criteria are used in conjunction with a postmortem examination, the estimated TTD will be closer to the real TTD for a majority of whales. Consequently, together the two can be used as a useful tool to compare different hunting methods and to evaluate the skills of each whaler always provided that competent personnel collect the data and the same protocol is used for the data collection and the analysis. If neuropathology cannot be performed, the TTD will still, however, be overestimated in some animals.

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