STUNNING AND SLAUGHTER

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INTRODUCTION

I have been asked to be controversial and to pay particular attention to recent advances in the science of stunning and slaughter. The two most controversial issues amongst scientists who work in this area are CO_2 in pigs and religious slaughter of cattle, and so there are selective reviews for both these topics. In addition there is a section on ethical issues which it is hoped will stimulate some debate. As for recent developments in the science of the subject, I have tried to focus on the literature published during 1986 and 1987 to do with electrical methods of inducing a cardiac arrest at stunning, and, concussion stunning methods in cattle and sheep.

ETHICAL ISSUES

There are two ethical issues to do with stunning and slaughter which require a philosophical decision and so they would benefit from some form of debate. Firstly, should animals be rendered insensible to pain by the stunning method, or should they be rendered insensible? British law requires that they are insensible to pain. Whereas, Australian law stipulates that they must be unconscious. This is not just a matter of semantics. Recent research has shown that sheep can be rendered insensible to pain by electrical stunning and this can last for over 10 min during which time the animals regain overt consciousness. This was demonstrated by recording evoked cortical potentials in response to electrical stimulation of an incisor tooth. The tooth-evoked responses were obliterated by stunning, and the same responses were previously found to be absent during halothane anaesthesia, but recovered soon after withdrawal of the anaesthetic. So, they were thought to be a useful indicator of sensibility to painful stimuli.

The second issue concerns the question whether animals should be dead when a potentially painful procedure is performed on the carcass. It has been argued that instead the animal need only be irreversibly unconscious. Two examples which emphasise the relevance of this issue are as follows. Firstly, the Farm Animal Welfare Council in the UK have suggested that poultry must be dead before immersion in the scalding tank, and presumably the logic for this would also extend to pigs. Not all birds are dead, as judged by the corneal reflex, when they reach the scalding tank (Gregory, 1987). Secondly, with the likely move towards automation of carcass dressing procedures in red meat plants, it is important to minimise the handling time and hence the cost of processing the carcass. As a result, processors may wish to perform invasive procedures such as horn removal or hock cutting before the animal has had time to die.

RELIGIOUS SLAUGHTER OF CATTLE

Three ethical issues have to be considered when animals are slaughtered without any form of prior stunning. Firstly, is the restraining method unduly distressing to the animal? Secondly, is the cut painful, and thirdly, does the animal experience pain or undue distress whilst it is bleeding out?

The first issue is largely a technical rather than a scientific or religious matter, and at present it is felt on subjective grounds that the Cincinnati pen is less stressful than the rotary pens (FAWC 1985). There is no scientific evidence which approaches the second issue in a direct manner, and the arguments on this point are based on differences in intuition. Whether an animal experiences distress whilst it is bleeding out depends in part on the length of time it takes before it loses consciousness. Consciousness could be sustained for some time following carotid severance in cattle because there is an anastomosis between the occipital and vertebral arteries in this species which allows blood to continue to flow to the brain.

The effect of shechita in cattle was recently examined by Daly et al. (1988) using the time to loss of spontaneous activity and loss of somatosensory and visual evoked responses in the electrocorticogram (ECoG) as an index of the time to a profound form of brain failure. This experiment confirmed previous findings from Massey University that the time to loss of brain function is very variable between animals (Table 1). It is unlikely that the capacity for sustained brain function in some animals compromises their welfare when electrical stunning is used as part of the religious slaughter method (Gregory et al. 1988). However, this may not be the case when electrical stunning is not used. In this respect it is important to look for the cause of the variation in time to loss of brain function, with a view to ensuring a rapid loss of consciousness in all animals.

CARBON DIOXIDE

A number of pig processors tn Europe are thinking of changing from electrical stunning to CO_2. The main worry is that CO_2 stunning may be banned some time in the future on the grounds that the induction is unduly stressful. It would be useful, therefore, to summarise the evidence which relates to the stress effects of inhaling CO_2.

Sybesma and Groen (1970) performed an elegant experiment where they used the incidence of PSE meat (determined from semimembranosus pH_{45} and rigor values) as a stress indicator and compared four treatments. In the first treatment pigs were put through an Oval tunnel CO_2 unit at a commercial rate (180 pigs per hour). In the second treatment another group of pigs was put through the same CO_2 plant but in a more gentle

Table 1. Time to onset of changes in brain function following shechita in unanaesthetised adult cattle

	n	Mean sec (± sd)	Range sec
Onset of less than 10μV cortical activity	8	75 (48)	19-113
Loss of visual evoked responses	8	55 (32)	20-102
Loss of somatosensory evoked responses	7	77 (32)	32-126

Table 2. Major symptoms during inhalation of CO2 in man

	7.6% CO_2	10.4% CO_2
Number of subjects	42	31
Proportion of subjects experiencing		
- dizziness	21	42
- dyspnoea	31	32
- sweating	19	19
- faintness	0	23
- restlessness	0	16

manner (90 pigs per hour). In the third treatment pigs were put through the same equipment but on this occasion it was filled with air instead of CO_2. When the pigs left the Oval tunnel they were electrically stunned using 75V. Finally, in the fourth treatment pigs were not put through the Oval tunnel. Instead they were directed across its entrance and electrically stunned in the same manner. The incidence of PSE meat in the first 3 treatments was 9% and it was 1% in the fourth treatment, suggesting that it was the environment of the stunning unit rather than the gas itself which precipitated this condition.

The Compact stunner is thought to be less associated with PSE meat than electrical stunning (Larsen 1983) and so, by implication, it is said to be less stressful than the Oval tunnel.

The arguments that CO_2 stunning is an inhumane procedure are based on the assumption that the gas has an acidic flavour and is pungent when inhaled at high concentrations, plus the fact that it stimulates breathing frequency and may lead to respiratory distress and a sense of breathlessness. Unfortunately (for us) there are no documented reports of the symptoms of CO_2 inhalation in man at concentrations near to 70%. The most useful study is by Uripps and Comroe (1947) who described the major symptoms of inhaling 7.6% and 10.4% CO_2 (Table 2). Increasing the CO_2 concentration from 7.6 to 10.4% did not have any effect on the incidence of dyspnoea (breathlessness) and sweating; these two features being rudimentary physiological responses. Responses associated with failing consciousness (dizziness and faintness) however increased markedly with this small increase in CO_2 concentration. Of these major symptoms it is dyspnoea which is of greatest concern from the welfare point of view in pig stunning. In general, it is the presence of CO_2 (or respiratory obstruction) rather than the absence of O_2 that is largely responsible for this sensation, and so no benefit is likely to be obtained from supplementing the stunning gas with 02. The issue that has to be settled is whether at high CO2 concentrations unconsciousness in pigs sets in before or after this adverse symptom would be perceived.

Van Putten (1987) reported an interesting study in which the reactions to CO_2 stunning were examined in pigs held within a familiar pen. He stated:-

> "...it was quite clear that, initially, the pigs tried to escape from the situation in the familiar pen, quite vigorously. So from an ethological point of view the situation for these pigs was not unpleasant, but they tried to escape from that familiar pen, and then afterwards they were unconscious, of course. After regaining consciousness they did not want to enter this pen again, although their only possibility to get water was via this pen. They remained thirsty for three days rather than enter this pen again, so there must be something very unpleasant in CO_2 stunning."

However, we do not learn from this study whether the aversive effect was due to the stress of induction or the hangover associated with recovery from CO_2 intoxication.

CO_2 stunning can be associated with convulsive behaviour which may be confused with escape behaviour. Forslid (1987) found that the physical convulsions occurred after the onset of high amplitude low frequency activity in the EEG, and so it was suggested that the pigs were unconscious by this time. Zeller et al. (1987) on the other hand suggested that the pigs appeared to be conscious during part of the convulsive episode.

Gregory et al. (1987) recorded vocalization in pigs immersed in a CO_2-filled Compact stunner, and found that between 24 and 27 sec after the start of immersion vocalization doubled. Whether this was due to the physical environment or the gas was not established, but it suggested that the experience was disturbing at this time.

In one of the early studies on CO_2 stunning, pigs were followed into a CO_2 filled room by a man wearing a respirator (Blomquist 1957). The pigs took about 15 sec to fall over, and the physical response to treading on their hooves with a pair of clogs was lost at 20 sec after exposure to the gas. Gregory et al. (1987) found that CO_2 produced a very profound stun when used at more than 80%. In Britain the recommended concentration is 62 to 70%. Dodman (1977) found that with concentrations in the range of 66 to 70%, about half of his pigs were standing within one minute of their return to atmospheric air. When 76 to 80% CO_2 was used, all the pigs were still lying on their sides for over a minute after removal from the CO_2 unit. The former observation emphasises the importance of sticking quickly when using low CO_2 concentrations. Where sticking cannot be performed soon after stunning, it would be safer to use the higher concentrations.

INDUCING A CARDIAC ARREST AT STUNNING

There are two distinct humanitarian advantages in inducing a cardiac arrest at stunning. Firstly, it results in a prompt and punctual kill. This is shown for five species using the loss of the visual evoked response as an index of brain death in Table 3. This method resulted in a quicker kill in pigs, chickens and ducks, and it would also be quicker in sheep where the time between stunning and sticking is greater than 14 sec. The main exception is the turkey, which dies more quickly when it has both carotid arteries cut in comparison with inducing a cardiac arrest. The second humanitarian advantage is that the efficiency of slaughter does not depend on the accuracy of the man or machine doing the sticking. From the welfare point of view it is no longer important which blood vessels are cut, whereas, when the heart is beating it is important to ensure that both carotid arteries are cut to prevent the animal regaining consciousness.

The ways of achieving a cardiac arrest at stunning are well documented for sheep (Blackmore and Delany 1987), and in the case of pigs the recommendation is to use 1.3 amp (250V) for 3 to 4 sec when applying head to back electrodes. This level will induce epileptiform activity in the ECoG plus a ventricular fibrillation in 99% of the pigs (Scott, in preparation). It is easier to fibrillate the heart in pigs when current is flowing along a dorsal-ventral path in comparison with transverse flow through the chest (Roy et al. 1986). The likely reason for this is that with the dorsal-ventral axis more current flows through the apex of the heart, which is the most sensitive region of the heart to the induction of a ventricular fibrillation (Roy et al. 1987).

Table 3. Time to loss of visual evoked responses following slaughter, sec ± SE

Slaughter method	Cattle	Sheep	Pig	Chicken	Duck	Turkey
Cardiac arrest		28±1	19±1	90±8	115±7	90±3
2 carotid arteries	55±11[a]	14±1	18±1[b]	163±1	172±28	64±5
1 carotid + 1 jugular		70±2		302±3		

a Vessels severed in mature conscious cattle whereas other studies performed in anaesthetised animals
b Common brachiocephalic trunk

In the case of sheep and pigs there are commercial advantages from inducing a cardiac arrest at stunning. These can include: less blood splash (Gilbert and Devine 1982), reduced susceptibility to carcass bruising (Gregory and Wilkins 1984), and a more relaxed carcass which is easier to handle (Gilbert et al. 1984). The blood content of meat and hide are not adversely affected (Chrystall et al. 1980; Gregory et al. 1985). In pigs the amount and rate of blood released from the sticking wound are normal provided the animal is stuck within 3 min of inducing the cardiac arrest. After that time it is thought that intravascular fluid passes to the interstitial space. Low molecular weight proteins (including some clotting factors) pass with this fluid, and thus blood in the capillary bed does not clot. Blood in the large veins and arteries, which have relatively thick impermeable walls, does not undergo this transition and so it clots quite readily. The net effect is that when sticking is delayed for more than 3 min the blood becomes dark through haemoconcentration, intravascular blood volume declines, clotting occurs in the chambers of the heart and large blood vessels, and the blood yield at sticking is low. These effects are not important in routine slaughterhouse practice but they are more real in the case of on-farm casualty slaughter or the slaughter of wild or game species.

In the case of adult cattle, the initial bleeding rate can be slower when there is an cardiac arrest at sticking, but by 4 min after sticking the total blood yield is the same as for carcasses which did not have a cardiac arrest. If the carcass which has a cardiac arrest is left for too long before it is bled, blood gravitates into the lower regions. The sites that become engorged with blood depend on the position in which the carcass is held, but, in the carcass that is suspended by a hindleg, the forequarter subcutaneous fat, large blood vessels of the shoulder, thymus and lungs show the greatest blood infiltration. Forequarter muscle can also have high haem pigment concentrations (Gregory et al. in press).

In the case of the poultry species there is more cause for concern about the quality aspects of inducing a cardiac arrest at stunning. Problems such as broken bones, blood spots in muscle, haemorrhaging of wing veins, and red wing tips are said to occur with high currents, but it has yet to be established whether the currents that produce these effects are higher or lower than that necessary to induce a cardiac arrest in all the birds. The current that induces a cardiac arrest at stunning in 99% of broiler chickens is 148 mAmp/bird, and for cull layer hens it is 136 mAmp/bird (Gregory and Wotton 1987).

RECENT ADVANCES IN CONCUSSION STUNNING METHODS

Daly et al. (1987) used the abolition of evoked potentials in the brain as an index of effective captive bolt stunning. It was found that increasing the speed of the bolt from 47 to 58 $m.sec^{-1}$ decreased the incidence of poor stunning from 67% to 39%. Subsequent work has shown that increasing bolt speed to 72 $m.sec^{-1}$ did not produce any further improvement (Daly 1987a). The normal range in bolt velocities in Britain is 34 to 61 $m.sec^{-1}$ when fired in air, and occasionally it is as high as 71 $m.sec^{-1}$. So the conclusion is that present guns do not always produce a perfect stun in terms of the above physiological criterion. The fact that evoked potentials were still present in a proportion of animals even at very high velocities could suggest that bolt speed is not the only important determinant of effective stunning. Theoretically it is the kinetic energy that is imparted to the animal's head which results in an effective stun. The transference of that energy will depend not only on the speed of the bolt but also on the bolt's cross sectional area.

The kinetic energy absorbed by an animal's head can be estimated from the difference between the speed of the bolt as it enters the brain subtracted from the speed that the bolt would have possessed had it been fired in air. This approach was used by Daly (1987a), and it became clear that the energy transmitted to the animal was more dependent on bolt diameter than on bolt speed. Increasing the diameter by 22% nearly doubled the energy loss when bolt speed was kept constant. Whereas, keeping bolt diameter constant while increasing bolt speed by 37% resulted in an increased energy loss of only 15%.

Another feature of gun design which should not be overlooked is whether the bolt (before firing) projects beyond the muzzle or is recessed within the barrel. The recessed bolt is to be preferred as it will have more room to accelerate before it strikes the head, and thus have a higher impact velocity. Poor gun performance can occur when carbon from the exploded charge condenses within the gun and prevents the bolt from returning fully back to its starting position between shots. This leads to an enlarged expansion chamber, which the exploding gas has to fill in order to propel the bolt, and loss of power.

Captive bolt stunning in the back of the head (poll position) can be associated with rapid recovery of brain function in sheep (Daly and Whittington 1986) and for this reason it is not generally recommended as the correct shooting position. Instead, sheep should be shot through the top of the head, but if horns make it necessary to use the poll position it is important to stick quickly. Shooting cattle in the poll position is not recommended for the same reasons (Daly 1987b). Recent evidence confirms the observations of Lambooy (1982) that it is the concussive rather than the invasive effect of the captive bolt that produces the stun (Daly 1987a).

AREAS REQUIRING FURTHER RESEARCH

To conclude this paper I would like to nominate some areas that require research and development in the future:-

1. It has already been mentioned there are gaps in our knowledge about the humaneness of CO_2 stunning in pigs.
2. The commercial effects of inducing a cardiac arrest at stunning still require evaluation in the case of poultry.
3. Electric shocks prior to stunning is a particularly serious problem in turkeys, because their wings often dip into the waterbath before their heads.
4. There is a need to devise safe and inexpensive constant current or current limiting circuits for electrical stunners. A New Zealand company has taken the lead in this area with a lamb stunner, and this should be extended to other species.
5. We also require better methods of presenting the head for captive bolt stunning in cattle. There are two approaches to this: head capture systems or encouraging the animal to raise its head.
6. Shoulder haemorrhaging can be a severe problem where pigs are electrically stunned in V type restraining conveyors. CO_2 stunning is an expensive way of avoiding this problem; head to back stunning with a squeeze box restrainer would be a cheaper alternative but it may not achieve the throughput required by larger plants. Are there any other alternatives?
7. Does electrical stunning cause instantaneous unconsciousness? It does not appear to induce epilepsy in the brain instantaneously; what about unconsciousness?

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