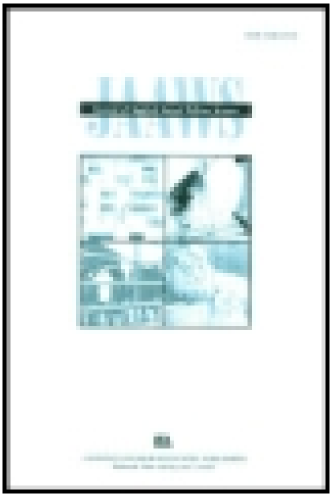

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Penetrating Captive Bolt Stunning and Exsanguination of Cattle in Abattoirs

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Abattoirs commonly use penetrating captive bolt pistols to stun cattle. Humane slaughter requires that an animal immediately becomes unconscious and does not regain consciousness. In this review we consider the concepts of concussion, unconsciousness, and return to consciousness. We conclude that an animal effectively stunned with a penetrating captive bolt pistol, as indicated by the presence of certain signs and the absence of others, has little possibility of brain function returning. Appropriate monitoring at all stages between stunning and sticking would ensure immediate detection and restunning on those few occasions when brain function was returning. When a captive bolt irreversibly stuns animals, sticking has no role in terms of animal welfare; its only function is to relieve the carcass of blood. With effective initial stunning and subsequent monitoring, specifying a stun-to-stick interval appears unnecessary. Abattoir surveys have indicated that it is possible to approximate, or even actually obtain, 100% successful stunning from a single shot. Furthermore, low prevalence of recovery follows. Thus, penetrating captive bolt stunning can form part of a process for the humane slaughter of cattle. This article outlines an approach to implementing standard operating procedures for checking the effectiveness of captive bolt stunning.

With the exception of certain forms of religious slaughter, “humane slaughter” of an animal in an abattoir normally involves (a) restraint to prevent injury to employees and enable the stunning device to be placed on the head accurately and applied effec-

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tively, (b) stunning to cause instant loss of consciousness, and (c) sticking (severance of major blood vessels) leading to exsanguination that results in loss of blood supply to the brain and irreversible brain death. If the stunning method causes irreversible loss of consciousness (as a result of severe brain trauma), exsanguination is needed only to relieve the carcass of blood. Slaughter could be considered inhumane only when the animal is conscious and has a functioning brain capable of perceiving pain or fear.

This article provides an overview of present thinking about the control of consciousness in the brain and reviews current scientific knowledge about whether penetrating captive bolt stunners applied to the frontal areas of the head reliably cause permanent loss of consciousness. This knowledge is used to both assess the risk of recovery of consciousness and evaluate the need to specify stun-to-stick intervals.

CONCEPTS OF CONCUSSION AND UNCONSCIOUSNESS IN HUMANS

To understand the working of the brain during consciousness, it is helpful to consider the three major divisions of the brain: forebrain, midbrain, and brain stem. The cortex of the forebrain can be divided into two functional components: the primary cortex and the association cortex. The primary cortex is the first part of the cortex that receives sensory input from afferent pathways. Responses in the primary cortex occur during both the anesthetized and unanesthetized states, so a response or activity in the primary cortex does not denote consciousness. The speed of a response, however, is influenced by anesthesia, and so certain patterns in the activity or response in this part of the brain have been useful experimentally in qualifying consciousness. Responses in the primary cortex are essential for conscious perception; without them, conscious perception for the modality that part of the cortex serves would not occur. But the signal in the primary cortex has to be transmitted to other regions of the brain before perception and interpretation—which take place in the association cortex—occur (Sieb, 1990).

An example of a projection from the primary cortex to an association cortex is that by which impulses pass from the occipital—primary visual—cortex to the posterior parietal cortex and the inferior temporal cortex. In the posterior parietal cortex, the object in the visual field is recognized as to where it is; in the inferior temporal cortex, the object is recognized as to what it is. In the case of the somatomotor association cortex, parts of the association cortex are in the frontal lobes of the brain and are involved in planning movements. They are connected to the somatomotor cortex, which controls muscle activity in the body. The somatomotor cortex is situated on the rostral margin of the central fold (sulcus) facing the somatosensory cortex. Different parts of the somatomotor cortex are responsible for activating different parts of the body.

The circuitry in the brain that serves a wide range of conscious perceptions and behavior is now well understood (Carlsson, 1994). Part of this understanding has come from clinical reports of damage to specific brain regions. For example, there are instances where the visual association cortex has been damaged and the subjects have been unable to recognize an object by sight but could recognize it by feel. Similarly, when the auditory association cortex has been affected, there can be difficulty in perceiving and producing meaningful speech.

The important conclusion is that the association cortex is essential for higher levels of consciousness such as perception, recognition, and thinking (Carlsson, 1994). However, the association cortex is not essential for more rudimentary aspects of consciousness such as the ability to be aroused or the ability to walk.

Consciousness and Unconsciousness

Consciousness is not invariably an all-or-none phenomenon. Degrees of consciousness disturbance can exist during concussion. Before we describe these, however, it is worth considering some other features of normal consciousness.

Consciousness encompasses sensory information that provides or allows awareness and emotions in response to the awareness and thought. The sensory modalities in consciousness include vision, hearing, balance, touch, kinesthesia, taste, smell, heat, cold, and pain.

These sensations, along with learned experiences, help produce thoughts and emotions. Some sensations and emotions, such as hunger, are involuntary but not subconscious, whereas some complex actions can be either involuntary or voluntary, occurring while the subject is either subconscious or conscious. Examples of these include scratching when asleep or awake, teeth grinding, or talking in one's sleep. Paradoxes like these can make the assessment of consciousness or unconsciousness in certain situations difficult. Physical responses to some types of nociceptive stimuli can occur at both conscious and subconscious levels and can add complications when attempting to establish whether an individual (human or nonhuman) is insensible to pain.

Although in some situations the interface between consciousness and unconsciousness can be difficult to define, during concussion consciousness can be quickly switched off, and the interface is defined more distinctly. Unconsciousness can be virtually instantaneous when a subject is struck on the head. Recovery also can be abrupt, but it is often associated with absence of memory (Gasquoine, 1997). This raises the question of whether there are key areas in the brain that can control the switch between consciousness and unconsciousness. To help answer this, we examine some experiences that humans had when operations were performed on the brain without a general anesthetic. In the past, it was recognized that local anesthesia was an effective method—and usually the safest one—to use during intracranial surgery.

During these operations, it was found that the whole cortex of one diseased cerebral hemisphere could be removed without disturbing consciousness (conscious awareness). On the other hand, rapid changes into and out of coma sometimes occurred when regions of the brain stem and third ventricle were manipulated. For example, light pressure against the surface of the medulla was capable of producing unconsciousness (Cairns, 1952). In one case, unconsciousness was produced by needle puncture of the medulla oblongata:

> The patient had previously had six uneventful cisternal punctures [in which a needle is inserted through the foramen magnum to the subarachnoid space below the cerebellum and dorsal to the medulla to tap cerebrospinal fluid]. The seventh was attempted with her sitting up, but only a few drops of venous blood were obtained. She was therefore placed recumbent on her left side and the needle was reinserted. At the moment when the needle entered the cranium the patient's head gave a sudden short backward movement and she rolled backwards, with the result that the needle which was already deep in the cistern, if not in the medulla oblongata, was driven about 2 or 3 cm deeper. It was immediately withdrawn, and at the same moment the patient cried out, clutched at her side with both hands, and was motionless, with open staring eyes. There was no response to loud calls. She remained thus for 10 to 15 seconds. Then her eyes began to move, and she leaned slowly forwards and began to rub her right leg, saying in an expressionless voice, "My leg, my leg." Then she recovered her normal liveliness and said, "Please repeat the puncture." When fully recovered the patient's account was that the needle was already in and not painful when suddenly she felt a jab and a shock run through the whole of her right side. Everything went black before her eyes. It was as if she suddenly saw her whole life rush past her like lightning. Then she lost consciousness. Later she heard her name being called from a long way off, and gradually awoke. She had the feeling that the whole of her right side, and especially her right leg, did not belong to her. (p. 125)

Puncturing the medulla has not produced unconsciousness in all cases. In some, it has produced a sudden sense of dying. Patients have been known to cry out, "I am going to die," but this might have been due to a disturbance of breathing. In other cases where unconsciousness occurred, this effect was said to precede respiratory and circulatory failure or disturbance.

The regions of the brain stem that can provoke immediate unconsciousness when lightly manipulated or damaged include the lamina terminalis, roof of the third ventricle, thalamus, pons, reticular formation, and medulla. Lesions of the thalamus can be associated with coma, tonic fits, decerebrate rigidity, seizure states resembling petit mal, hypersomnia, and akinetic mutism. Milder interference can produce unconsciousness associated with petit mal seizures. Unconsciousness can be induced readily by physical manipulation of the anterior part of the third ventricle.

Usually there is no effect on consciousness from puncturing the frontal lobes of the cerebrum of the brain with a needle, so long as it is not associated with a concussive blow. In addition, massive bilateral ablation of the frontal lobe does not disturb crude consciousness, but it does disturb the will, initiative, foresight, and inhibitory powers (Carlsson, 1994). Removal of the whole forebrain, which would include the thalamus, would be more catastrophic and would cause unconsciousness in humans.

Grades and Depths

When only the brain stem and thalamus are present, the subject can sleep and wake; breathe; swallow; grimace; respond to painful stimuli; and react to hunger, loud sounds, and crude visual stimuli by movement of the eyes, eyelids, and facial muscles. Subjects might be able to taste and smell, reject unpalatable foods, and accept foods they like. They might utter crude sounds, cry and smile, or show displeasure when hungry and pleasure (in a babyish way) when sung to. In addition, they might perform spontaneous, crude movements of their limbs. None of this is what psychologists consider consciousness.

In many situations there are grades or depths of unconsciousness. There are degrees of recovery of consciousness for which we have no precise terminology that describes the states between coma and full consciousness. Take the following example:

> On July 16, 1944, a young soldier received a severe wound to the left cerebral hemisphere and cerebellum. On the second day the track of his left parietal wound was cleaned out down to the posterior horn of the left ventricle, and his wound healed without infection. At first he was in a deep coma, and his residual deficiencies only gradually became apparent as his unconsciousness gradually lessened.
> July 17: deeply unconscious and inert, but cried out if interfered with.
> July 23: opened his eyes when called by name.
> July 26: more alert. He had right hemiparesis and aphasia.
> Aug 5: can now hold short conversations.
> Aug 12: speech improving and he proved to be emotionally facile. His visual fields could now be tested and he proved to have complete right side blindness in the brain.
> Aug 17: severe sensory loss in his right limbs.
> Sep 11: he remembers being hit, but thereafter nothing for at least two weeks and probably more.
> Dec 16: he finds that he has difficulty in grasping the meaning of a picture. (Cairns, 1952, p. 111)

Clearly, recovery in this case was protracted with no distinct interface between consciousness and unconsciousness, and we have no exact words that describe the gradations in recovery.

Impairment Criteria

There also are gradations in the induction of unconsciousness. Concussion that occurs during boxing contests, for example, can be divided into four stages or depths (Parkinson, West, & Pathiraja, 1978). In Stage 1, there is impairment of memory, but motor control and activity are normal. In Stage 2, there is impairment of memory and motor activity, and the individual is clumsy and slow and does not show controlled or fully coordinated physical responses. In Stage 3, motor activity ceases except for breathing, which might, however, be impaired or somewhat irregular. The subject is unable to stand. In Stage 4, the medulla is affected, and breathing ceases. The medical attendant at a boxing match is particularly watchful for Stage 4 concussion, because this potentially is lethal if respiration cannot be reinstated.

Respiratory arrest is a useful criterion of brain stem impairment and unconsciousness during concussion. However, breathing does not necessarily signify consciousness. For example, spontaneous breathing occurs in the first three planes of Stage 3 anesthesia, during which the individual is anesthetized sufficiently to be subjected to surgery (Lee & Atkinson, 1973). Absence of a corneal reflex also can be used to assess the depth of concussion. If the reflex is absent, it can be concluded that the pathway leading to the optic chiasma and brain stem and back to the eye through the effector pathway has been affected. It is usually assumed that this is due to disruption of function in the brain, but in some circumstances it could be due to concussion of the optic nerve. Theoretically, optic nerve impairment after concussion could occur in two ways: (a) failure of function without structural damage—for example, by concussion of the nerve within the foramen of the orbit (neurapraxia) and (b) failure associated with damage to the nerve fibers from compression of the optic nerve (axontomesis). This could be due to compression by a hemorrhage that has leaked into the optic nerve sheath from the ophthalmic artery or from edema impinging on the nerve (Karnik, Maskati, Kirtane, & Tonsekar, 1981). There is no simple way of distinguishing between neurapraxia or axontomesis and disruption of the neural pathway within the brain.

Respiratory arrest is the most immediate life-threatening consequence of brain injury. In the longer term, a raised intracranial pressure also threatens the survival of the individual. This raised pressure occurs when hemorrhage or edema follows the insult. If intracranial pressure exceeds the localized or generalized arterial pressure of the blood in the brain, there is a risk of arterial compression or collapse, hypoxemia, and permanent brain damage. In noncomatose humans, raised intracranial pressure often is associated with reduced systemic blood pressure, which could increase the likelihood of arterial collapse in the brain (Bailey, 1942). As intracranial pressure increases, the onset of coma is abrupt, and in the human, coma occurs once the hemorrhage exceeds 8% of the cranial cavity volume (Steiner, Bergvall, & Zwetnow, 1975). The raised intracranial pressure also could affect brain stem function directly by pressing onto that region. Lateral displacement of the brain stem region more frequently seems to be associated with unconsciousness than vertical compression (Ropper, 1989).

Summarizing this evidence, we can conclude the following: A functioning association cortex is essential for mental activity and for higher planes of consciousness—memory, perception, recognition, and thinking—and a functioning brainstem and thalamus are essential for rudimentary forms of consciousness in humans.

No one region in the brain is a center for consciousness (Dimond, 1976). However, damage to regions in the brain stem is associated with a rapid onset of complete unconsciousness. This indicates that when concussion causes interference to the brainstem, it is likely to be particularly effective in inducing unconsciousness.

Although the induction of unconsciousness during concussion can be abrupt, recovery is not invariably so rapid. There are situations where recovery is phasic and only partial, and this can make it difficult to qualify the presence of consciousness or unconsciousness.

When concussion is accompanied by the absence of respiration due to interference with the medulla in the brain stem, the concussion is particularly deep. The absence of breathing is a valuable guide to the depth of brain stem disturbance and concussion.

CAPTIVE BOLT STUNNING

Numerous references confirm that captive bolt stunning with a penetrating bolt can produce immediate unconsciousness. Lambooy and Spanjaard (1981) used electroencephalogram (EEG) recordings to investigate the humaneness of captive bolt stunning of cattle. They concluded that frontal stunning almost certainly ensured immediate unconsciousness because delta and theta waves (as seen during anesthesia) appeared on the EEG directly after stunning. Daly, Gregory, Wotton, and Whittington (1986) used somatosensory and visual-evoked responses to evaluate brain function after captive bolt stunning in sheep. They concluded that captive bolt stunning produces immediate and profound brain failure.

There are differences of opinion as to whether the stun consistently produces permanent insensibility. Blackmore and Delany (1988) stated that when a captive bolt pistol stuns animals (species not specified) in the correct position in the frontal region with a projectile of sufficient velocity, insensibility is immediate and permanent. Similarly, Daly, Gregory, and Wotton (1985) found that visual-evoked responses—which when present indicate that the brain is functioning—were not present in sheep for the 5-min period between captive bolt stunning and exsanguination. Finnie (1993) examined the neuropathological changes produced when a penetrating captive bolt pistol was used on sheep. He concluded that the pistol probably produces rapid unconsciousness but stated that captive bolt stunning should be followed immediately by further actions to ensure that the animal is rendered permanently unconscious. In a subsequent article, Finnie (1997) also implied that unconsciousness after captive bolt stunning may not be permanent, and therefore exsanguination is necessary to ensure certain death.

Testing the Stunning

The effectiveness of captive bolt stunning in obliterating visual-evoked responses in the cortex of the brain depends on the velocity of the bolt (Daly, 1987; Daly et al., 1985). This was tested by using different cartridge strengths in a gun with interchangeable bolts. The heads of different bolts had been milled to vary the volume of the expansion chamber. A fiberoptic device attached to the end of the gun measured bolt velocity and detected the rate at which grooves that had been imprinted on the shaft of the bolt passed through the gun's muzzle. Visual-evoked responses were assessed with the method of Gregory and Wotton (1983). The effect of captive bolt stunning on the visual-evoked responses was divided into three categories. First, in some animals the visual-evoked responses were immediately abolished. Second, some responses were not abolished. Third, some responses were lost but subsequently recovered. The immediacy of the loss was determined by averaging the first 4 sec after the stun, and this included eight stimulus-response periods. The prevalence of visual-evoked responses immediately after stunning with 47 m/sec^{-1} was 4 of 7 animals (57%). This dropped to 10% at both 55 m/sec^{-1} (1 of 11 animals) and 72 m/sec^{-1} (1 of 9 animals).

Using cartridges of lower strength than those recommended by the manufacturers can increase the incidence of poor stunning. Work by Daly and Whittington (1989) and Daly (1991) in more than 2,500 cattle showed that effectiveness also depended on the type of animal (bulls being more difficult to stun effectively than other classes of cattle) and accuracy of shooting position. In that work, the researchers assessed effectiveness by examining the shot animal for signs of poor stunning. Those signs included repeat shots, rolled eyes, and rhythmic breathing (excluding gagging). From work with the prevalence and recovery of visual-evoked responses, the signs were considered to indicate suboptimal stunning. The researchers evaluated shooting position in the skinned heads by using a perspex sheet bearing a 22 × 18-cm grid. The grid was positioned with a line across the back of the eyes and with the origin over the lateral corner of the left eye. A value for the midline and *x,y* coordinates of the shot were then obtained. This was used to calculate the distance of each shot from the “ideal” position, which was taken to be 7 cm behind the line across the back of the eyes ± 1 cm in the anterior–posterior and lateral directions. The distance of the shot from the ideal was, therefore, the hypotenuse of the resultant triangle. In a survey of 27 abattoirs, the prevalence of shots in excess of 5 cm from the ideal position was 8% (Daly & Whittington, 1989).

Assessing Energy

The success in obliterating visual-evoked responses depends on the energy imparted to the head of the animal. This can be calculated from the rate of deceleration of a bolt of known mass on striking the head and before the compressible rings inside the gun take up the bolt’s energy. The rate of deceleration can be assessed with the fiberoptic velocity sensor referred to earlier. Using this approach, in conjunction with the effect on visual-evoked responses in the brain, we have confirmed that the prevalence of absence of evoked responses increases with energy transfer and that energy transfer tends to increase with bolt diameter (Table 1).

If there is the possibility of animals recovering from the stun, then presumably the sooner an animal is stuck, the less the chance of recovery. Thus, in the interests of animal welfare, the concept of specific stun-to-stick intervals has been suggested. However, if one can be certain that the effect of the captive bolt stun is permanent, then it is unnecessary to define a stun-to-stick interval. The effect of the captive bolt stun is unlikely to be permanent if the stun is initially ineffective. Thus, the first step in ensuring humaneness of the slaughtering procedure is to confirm that the stun has been effective. The signs of an effective stun (Fricker & Riek, 1981; Grandin, 1983, 1998a, 1998b) include the following:

TABLE 1
Effect of Bolt Speed and Bolt Diameter of a Captive Bolt Gun on Energy Transfer to the Head of the Animal and the Prevalence of Visual-Evoked Responses in the Cortex of the Brain

	Bolt Speed (m/sec^{-1})			
	47		*55*	
Bolt Diameter (mm)	*Energy Transfer*	*Evoked Responses*	*Energy Transfer*	*Evoked Responses*
12	97 + 17	3/6	124 + 25	1/8
14	125 + 18	2/8	139 + 25	1/8
16	158 + 20	1/7	186 + 30	0/7

1. Immediate collapse.
2. Brief tetanic spasms that might be followed by uncoordinated hind limb movements.
3. Immediate and sustained cessation of rhythmic respiration.
4. Absence of coordinated attempts to rise.
5. Absence of vocalization of animals.
6. Glazed “glassy” appearance of eyes.
7. Absence of eye reflexes.

The presence of the corneal (blink) reflex at any time after captive bolt stunning casts doubt on the effectiveness of the stun. This reflex can be tested by lightly touching the surface of the eye. The closure of the eyelids indicates the presence of the reflex. The corneal reflex depends on an intact ophthalmic nerve to carry the stimulus to the brain and an intact facial nerve (cranial nerve VII) to control the eyelid muscles (King, 1987). Although theoretically it is possible for one or both of these nerves to be concussed or destroyed by the captive bolt itself, studies with sheep suggest that this is unlikely the case (Daly et al., 1986). Part of the nervous control responsible for the expression of the corneal reflex is located in the brain stem, close to the region of the brain associated with the maintenance of sensibility through the reticular system. Again, it is possible that only that part of the brain stem controlling the corneal reflex might be damaged. Thus, once again there is the theoretical possibility of a corneal reflex being absent, even though other brain stem functions are present.

Corneal Reflex as Indicator

In practice, however, it appears that the corneal reflex is a useful indicator of the effectiveness of a captive bolt stun. Lambooy, Spanjaard, and Eikelenboom (1981) demonstrated the presence of the corneal reflex in two veal calves after concussion stunning with a mushroom-headed stunner. In both cases, the EEG pattern indicated that the calves had not been stunned effectively. Similarly, seven calves shot in the nape of the neck with a penetrating captive bolt pistol were fully conscious, according to the EEG, as long as there was a corneal reflex (Lambooy & Spanjaard, 1981). Schutt-Abraham, Wormuth, Fessel, and Knapp (1983) stunned 11 sheep with a penetrating captive bolt pistol. All 11 shots resulted in an immediate extinction of the corneal reflex and, in all but one case, immediate cessation of respiration. A nonpenetrating captive bolt pistol stunned 7 animals. In 4 animals, there was no loss of the corneal reflex, whereas in 1 additional animal the reflex was lost for about 1 min before returning. In 2 animals, the corneal reflex ceased immediately after the shots. The authors concluded that there was an evident correlation between the extent of the cranial damage and the cessation of the corneal reflex.

Shaw (1989) found the corneal reflex to be absent in 97 of 100 animals—including cattle, calves, sheep, and goats—stunned with a penetrating captive bolt pistol. The reflex was tested within 15 sec of stunning, and all animals were judged, according to the criteria of Fricker and Riek (1981), to have been stunned effectively: immediate collapse, no attempt to stand, glassy eyes, and failure of respiration. In the series of 100, 2 of the remaining 3 animals could not be tested because the eye remained closed, whereas a corneal reflex was present in 1 calf who otherwise was judged to have been stunned effectively.

Thus, the majority of the evidence in the literature demonstrates that animals who have been stunned effectively do not have a corneal reflex, whereas the reflex is present in animals who have been stunned ineffectively. This knowledge could be applied to ascertain whether there is justification on welfare grounds for a particular stun-to-stick interval.

HUMANENESS OF THE STUNNING–STICKING PROCEDURE

If all of the signs of an effective stun, including the absence of a corneal reflex, are present immediately after the stun and the corneal reflex is still absent just before sticking, then it is reasonable to suppose that the stunning–sticking procedure is humane. This would apply regardless of the stun-to-stick interval. Thus, if the employee responsible for sticking tested the corneal reflex on each animal just before sticking and the reflex was absent, then one could be reasonably certain that the stunning–sticking procedure was humane.

A positive corneal reflex can occur in both conscious and unconscious animals and thus does not distinguish between these states (Gregory, 1998). Therefore, the presence of a corneal reflex in a stunned animal does not constitute proof that the stun was inhumane or that the animal is presently conscious. Furthermore, recovery from an ineffective stun is likely to be progressive in that the animal will gradually pass from an unconscious to a conscious state. In these circumstances, the corneal reflex is likely providing a warning that the animal is in the process of regaining consciousness. In practice, it is possible to ensure the absence of the corneal reflex in almost 100% of animals on the bleeding rail (Grandin, 1998b), and the presence of the reflex should not be acceptable in a slaughter plant.

The ideal shooting position in the head depends on the species, velocity of the bolt, and the type of animal within the species (“Captive-Bolt Stunning,” 1993). It usually is assumed that the ideal position corresponds to the intersection between two imaginary lines drawn between the base of the horn and the corner of the eye on the opposite side of the head. This recommendation stemmed from the position that was recommended during the 19th century for striking an ox with a poleax (Gregory, 1989). In sheep, shooting in the poll position at the back of the head is just as effective as the frontal position (Table 2). However, it is important to stick poll-stunned sheep promptly to eliminate the possibility of recovery of consciousness (Daly & Whittington, 1986). Poll shooting is not recommended for cattle because it is less effective in eliminating evoked responses (Daly, 1987). It seems logical to assume that the area of the ideal shooting position would increase with increases in the velocity of the bolt.

The evidence as to whether nonpenetrating (mushroom head) captive bolt stunning produces the same effect as penetrating stunning appears to be equivocal. Finnie (1995), in a trial with 12 adult cattle, demonstrated that nonpenetrating stunning always produced immediate loss of consciousness, but when this method was used to stun veal calves, Lambooy et al. (1981) reported that some animals were not rendered insensible at any time. It is possible that their poor results were due to underpowered cartridges rather than the use of a mushroom head. Daly (1991) compared stunning with mushroom head and penetrating bolt and found no difference in effectiveness as assessed by visual-evoked responses. In theory, pneumatic captive bolt stunners should have the same effect as cartridge-powered pistols; however, in practice, ergonomic difficulties often lead to poor stunning with this equipment (Grandin, 1998b). Abattoir employees involved in stunning and sticking operations must not be overloaded with tasks or overworked, because operator fatigue can lead to inappropriate stunning of animals and the necessity for additional stunning attempts (Grandin, 1998b).

Humane Stunning in the Abattoir

Even in the challenging environment of a commercial abattoir, it is possible to consistently stun cattle humanely. Grandin (1998b, 1999) assessed stunning efficacy in 19 beef plants, measured as percentage of cattle rendered insensible (absence of rhythmic breathing, vocalization, arched-back righting reflex, eye reflexes) with one shot from a captive bolt, and reported that 21% of these plants had a perfect score

TABLE 2
Effect of Shooting Position (Frontal vs. Poll) on the Prevalence of Evoked Responses in the Cortex of the Brain in Sheep and Cattle

	Prevalence of Evoked Responses During the First 16 Sec After the Shot	
	Frontal Position	*Poll Position*
Sheep	0/8	0/8
Cattle	1/11	6/8

of 100% for stunning efficacy. Furthermore, recovery from the stun was extremely rare. More than 1,000 cattle were observed on the bleeding rail, and only 1 animal showed obvious signs of sensibility. Poor stunner maintenance and poor ergonomics of bulky pneumatic captive bolts were the major causes of missed stuns when imperfect stunning occurred. Suitable animal restraint systems, possibly including neck restraint, are important in ensuring the humaneness of the stunning procedure, although care must be taken that the restraint system does not cause stress to the animal (Ewbank, Parker, & Mason, 1992).

The effectiveness of the stun depends on matching the right equipment (gun type and cartridge strength) for a given animal, the accuracy of the shooting position, and gun maintenance. These in turn depend to some extent on the suitability of the animal restraint system and on the skill and judgment of plant staff. It is important to assess each situation separately when deciding whether standards at a given plant are satisfactory and whether a delay in the time to sticking would be acceptable. This can be achieved by implementing a quality assurance scheme for each plant.

Recommended Requirements

It is recommended that plants include the following requirements in work instructions or standard operating procedures for their employees.

Check for effective stun. Examine all animals immediately after the stun for the signs of an effective stun and test stunned animals for the corneal reflex just before sticking.

Selection, training, and ongoing supervision and assessment of stunning operator. This should not be an area where casual employees are used. Employees need to have good training on how the device is used, where it is applied, signs of effective stunning, and what to do if the effectiveness of stunning is in doubt.

Backup stunning devices. There must be backup stunning devices immediately accessible and ready to use so that the animal can be restunned without delay.

Operational care and maintenance of stunning equipment An operator who believes the device is malfunctioning in any way should use a backup device immediately.

End-of-shift maintenance of stunning equipment. Manufacturers of captive bolt stunners generally recommend daily dismantling of the device for cleaning and checking. Ideally, the equipment should be checked with a velocity-measuring device before being returned for use.

Other employees. Employees working between stunning and sticking (e.g., shacklers) should have similar training as the operator performing stunning and should have ready access to a backup stunning device. If an animal is recovering from the stun, the aim must be to detect, restun, and bleed it before consciousness fully returns. Heads should be checked regularly for correct placement of the bolt. There must be good feedback to the stunning operator. In this way, it should be possible to achieve as close as possible to 100% compliance.

Verification activities by quality assurance officers. With the aim of assessing the level of compliance, it is suggested that at least 5% of stunned animals be observed for indications of inadequate stunning (respiration, vocalization, coordinated hind leg movements), checked for the corneal reflex just before exsanguination, and checked for bolt penetration in the correct anatomical location. If adequate compliance is found with these requirements, then it is likely that the entire procedure is humane, and it is unnecessary to specify a stun-to-stick interval.

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