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Assessment of stun quality at commercial slaughter in cattle shot with captive bolt

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Abstract

Cattle may suffer pain and distress if incorrectly stunned. Regular monitoring of stun quality in abattoirs is now required by EU law. This study aimed to assess stun quality in cattle slaughtered under commercial conditions. A stun protocol was developed to evaluate when inadequate stunning occurred. This included rating of identified symptoms into three levels from highest to lowest risk for inferior animal welfare. Stun to stick interval times, shot accuracy, repeat shots, and stun quality variations between different cattle classes and by different shooters was also investigated. A total of 585 bulls and 413 other cattle classes (306 cows, 58 steers and 49 calves) were studied. Inadequate stunning occurred in 12.5% (16.7% of bulls, compared with 6.5% other cattle). Bulls displayed symptoms rated the highest level for inferior stun quality three times more frequently than other cattle. Despite being shot accurately, 13.6% bulls were inadequately stunned compared with 3.8% other cattle. Twelve percent of cattle were re-shot, and 8% were inaccurately shot. Calves were shot inaccurately more frequently (14%) than other cattle. Percentage of cattle shot inaccurately ranged from 19% for the least experienced shooter to 5% for the most experienced. Stun to stick times averaged 105 (± 17) s posing questions for animal welfare, considering the number of cattle inadequately stunned. Stun quality could be improved by using more powerful stunners for shooting bulls, regular servicing of weapons, and use of neck restraints to improve shot accuracy. This study highlights the importance of external monitoring of stun quality at slaughter.

Keywords: *animal welfare, audits, captive-bolt stunning, cattle welfare, commercial slaughter, stun quality assessment*

Introduction

The protection of animals at the time of slaughter is a matter of public concern and regular monitoring of stun quality in abattoirs is now required by EU law (EC 2009). Animals are stunned prior to slaughter to ensure they are unconscious during the sticking and bleeding procedures until death occurs. Captive-bolt stunning causes an abrupt trauma to the skull, brain and associated blood vessels, and a subsequent array of physically displayed symptoms depending on where, how deep and at what velocity and kinetic energy the bolt enters the forehead and brain. Death may result as a consequence of the physical damage to the brain but it is not a guaranteed outcome (Appelt & Sperry 2007). The monitoring of stun quality in abattoirs is based largely on evaluation of the physical signs of consciousness, and an animal can be presumed to be insensitive when it does not show reflexes or reactions to stimuli such as sound, odour, light or physical contact (EC 2009). Legislation states that sticking should commence as soon as possible to reduce recovery risk (EC 1993). However, under commercial conditions, it may be difficult to quantify this risk in the event that certain symptoms are displayed. To properly assess stun quality, the adequacy of the stunning equipment and procedure must first be confirmed. In addition, signs of sensibility or awareness must be properly identified and the risk to animal welfare calculated so appropriate action (ie re-stunning) can be taken. Although symptoms such as failure to collapse, rhythmic breathing, blinking, corneal reflexes, righting reflexes, vocalisations, nystagmus and eyeball rotations should be absent after captive-bolt stunning (EFSA 2004; Gregory *et al* 2009), a degree of controversy exists as to the most reliable signs to measure stun effectiveness (Gouveia *et al* 2009).

In commercial slaughter, it should be possible to ensure adequate stunning in almost 100% of animals (Grandin 1998; Gregory & Shaw 2000). However, recent studies in cattle shot with penetrative bolt weapons confirm otherwise. Von Wenzlawowicz *et al* (2012) reported 9.2% cattle incorrectly stunned in commercial abattoirs, Gouveia *et al* (2009), 32%, and Gregory *et al* (2007), 9%. The last authors also found a higher prevalence of inadequate stunning in bulls, compared with female cattle (16 versus 6%). In abattoirs not equipped with restraint devices to hold the head (head gate), von Wenzlawowicz *et al* (2012) reported that 35% of cattle were inaccurately shot.

More than half of the 445,000 cattle slaughtered annually in Sweden are bulls, of which 89% are aged between 16 and 23 months and 11% older than 23 months (Official Statistics Sweden 2011). Such substantial proportions of entire males over 16 months of age could increase the risk of inadequate stunning. Due to technical design constraints in the stunning and sticking areas, stick times may exceed 60 s (contrary to Swedish regulation limits) and many abattoirs use captive-bolt guns with no equipment to restrain the head. In light of these concerns, the aim of this study was to develop and implement a feasible protocol for assessing stun quality during commercial slaughter where penetrative-bolt stunning is used. It also aimed to assess the stun to stick interval times, shot accuracy, and stun quality variations between different cattle classes, and by different shooters. Stun quality and shot accuracy were expected to be consistent in all cattle classes, and the majority of cattle stuck within 60 s after stunning.

Materials and methods

This study was conducted with the approval of the ethical committee in Gothenburg in accordance with Swedish regulations. A total of 998 cattle were assessed during routine stunning over five consecutive days at an abattoir processing, on average, 200 cattle daily and 30 animals an hour. There were 885 bulls (559 young bulls aged between 16 and 30 months and 26 mature bulls aged over 30 months), 306 cows (including heifers), 58 steers and 49 calves. For the purposes of the study, the animals were categorised into dairy breeds (Swedish Red and Holstein) and beef breeds (Charolais, Limousin, Simmental, Hereford and crosses).

Cattle were individually stunned in a 260 × 81 × 160 cm (length × width × height) steel-walled pen (stun box), which was not fitted with head or neck restraint gates. A shooter leaned over from an elevated platform and shot the animal in the forehead with a trigger-activated Cash Magnum 9000, 0.22 calibre gun (Accles and Shelvoke Ltd, UK). This fired a 121 × 11.91 mm (length × diameter) retractable bolt into the animals' brain. Three different grades of ammunition were used. Mature and young bulls were shot with cartridges 4.5 G, cows and steers with 4 G and calves with 3 G. Two of these weapons were available and used alternatively after each shift to reduce overheating. Three people worked in the stunning area (one shooting, one shackling, and one sticking), regularly alternating between shifts to reduce worker fatigue. There were five numerically identified shooters during the study. Shooter 1 shot on days 2, 3 and 4; shooter 2 every day; shooter 3 on day 3; shooter 4 on day 5 and shooter 5 on days 1, 2, 3 and 4.

Each stunned animal was ejected from the stunning pen when the side wall opened up, delivering the animal onto a steel table (stun crate). A person wrapped the animal's hind leg with a chain and fixed it to a moving shackle line for hoisting and transfer 6 m to an area for sticking. Prior to sticking, each front leg was chained and secured to a post to prevent the person doing the sticking from being kicked. With one knife, an incision was made above the brisket, cutting downwards through the skin until just under the animal's jowls, and the skin peeled away to expose the major blood vessels. A different knife (a double-edged blood-collecting knife), was used for chest-sticking procedures (severance of the large blood vessels that give rise to the jugular veins and carotid arteries in the thoracic cavity).

Stun quality

Two people assessed stun quality from stun to stick. The stun to stick interval was also recorded using a stopwatch (timed from when the shot was heard to when the knife was inserted into the chest). Stops or causes for delays during this phase were also recorded. Registrations were noted on the type of cattle shot, ie (dairy or beef breeds), cattle class (young bull, mature bull, cow [including heifers], steer or calf); the number of times it was shot; and who shot it (by numerical identification of the shooter). Based on guidelines for assessing animal welfare at stunning (EFSA 2004; Gregory *et al* 2007; von Holleben *et al* 2010), a stun quality protocol (SQP) was designed in a similar manner to Atkinson *et al* (2012), identifying symptoms of recovery and categorising them into three levels of stun quality, noted as the 'Stun Quality Rating' (SQR). This was to differentiate animals showing high risk signs of recovery and inferior animal welfare from moderate and low risk categories (Table 1). Adequate (deep) stunning (SQR0) occurred when animals showed immediate collapse, a tonic phase followed by a clonic phase of spasms and involuntary limb movements, cessation of rhythmic respiration, no attempt to regain posture, and absence of vocalisation, pain reflexes, corneal reflex or eyeball movements. Any symptoms outside of this criterion were recorded and registered as either occurring on the stun crate, shackle line or during sticking and given a stun quality rating. Symptoms including failure to collapse, vocalisation, blinking, corneal reflex, pain response, attempt to regain posture or rhythmic breathing, were considered signs of sensibility or imminent recovery and graded the highest risk rating for inferior stunning (ie SQR3). Nystagmus and full eyeball rotation were not considered as high risk as SQR3 symptoms and rated SQR2. Symptoms rated SQR1 (partial eyeball rotation, gasping, groaning, strong reactions at sticking, ears backwards, or tongue retained in the mouth at sticking) were recorded to find associations with the higher risk symptoms but were not considered direct indications of sensibility. Cattle with symptoms rated either SQR2 or SQR3 were considered inadequately stunned. A final score for stun quality was given from the highest rated symptom observed. Cattle were re-shot at the shooters' discretion if they saw cattle display symptoms rated SQR2 or 3.

Shot accuracy and repeat shots

The skull of each animal assessed at stunning was inspected after decapitation and skinning, and the shot location recorded using the diagram depicted in Figure 1. If the shot hole was registered in the 'A' area, it was considered an 'accurate' shot, ie located within a 2-cm radius of the intersection of two diagonals drawn between

Table 1 Stun Quality Protocol describing symptoms with ratings from 3 (highest) to 1 (lowest) risk for recovery and inferior animal welfare.

Stun Quality Rating (SQR)	Action	Symptom	Definition
SQR3*	Re-stun immediately	Failed to collapse	Animal does not immediately fall to the ground after shot with all legs collapsed
		Attempt to regain posture	Animal attempts to stand up or lift the head before hoisting
		Vocalisation	Repeat vocalisations or groans can be heard not associated with a one-time exhalation
		Pain response	Animal reacts to a painful stimulus such as a prick to the inner skin of the nostril with a sharp instrument while on the stun crate or shackle
		Blinking	Animal opens/closes eyelid on own (fast or slow) without stimulation
		Corneal reflex	Animal blinks (fast or slow) in response to stimulus of the cornea
		Rhythmic breathing	Continuous rhythmic inhalation and exhalation in the form of expansion/contraction of the trunk area can be seen or exhalations can be felt with the hand
SQR2*	Re-stun immediately	Full eyeball rotation	The eyeball rolls so mostly pink sclera can be seen and little or no iris
		Nystagmus	Rapid side-to-side (twitching) movements of the eyeballs
SQR1	Monitor closely and re-stun if ≥ 2 symptoms are observed	Absence of tonic/clonic phase	Absence of tonus in whole body and muscle spasms for over 20 s after stunning
		Partial eye rotation	The eyeball rolls so that only half of the iris is still visible
		Groaning	A groaning sound can be heard upon exhalation and not repeated
		Head raising	The head is flexed upwards while animal hangs on the shackle line
		Gasping	Repetitive contraction and retraction of the lips and slight opening/closing of the mouth
		Reactions to sticking	Severe kicking and body or head movements during skinning or sticking procedures
		Ears not pointing downwards	When the ears face backwards towards body at sticking and do not hang downwards
		Tongue up	When tongue is retained in mouth (not hanging down and relaxed out of mouth) at sticking

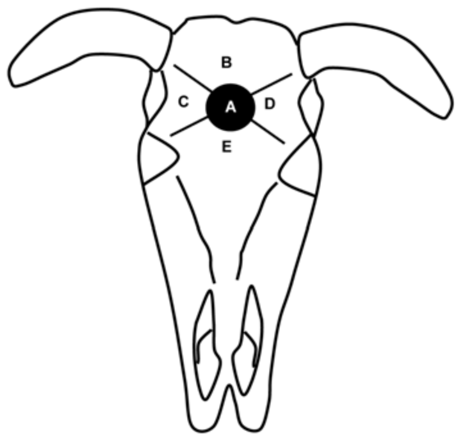
* If an animal shows any one symptom of SRQ2 or 3 it is considered inadequately stunned.

the base of the horns or upper edge of the ears contralateral to the opposite eyes (EFSA 2004; SJVFS 2008). Shot holes located more than 2 cm outside of this area were considered as 'inaccurate' and the relevant location registered (Figure 1). Using a body identification number for each animal, the breed, the cattle class, stun quality, number of times shot, shot location on the skull, and numerical identification of the shooter were correlated.

Data analysis

Effects on stun quality, shot accuracy and display of certain symptoms in different cattle classes and breeds were analysed using a marginal model and the generalised estimating equations approach using the GENMOD procedure of the Statistical Analysis System (SAS 9.2, SAS Institute Inc, Cary, NC, USA, 1999 to 2001). Animal class (bull or cow) and breed (beef or dairy) were introduced as fixed effects. Ninety-five percent confidence intervals were computed using the Pearson-Copper exact methods (Copper & Pearson 1934) for different cattle classes (bull, cow, steer

Figure 1



Shot holes found in the 'A' area depicted accurate shots. Shots outside of this area (> 2 cm from the crossover point) were considered 'inaccurate' and recorded as B (high), C and E (wide) and D low shots.

Table 2 Percentage of cattle classes showing symptoms SQR0, 1, 2 or 3, inadequately stunned, inaccurately shot, re-shot, and accurately shot but inadequately stunned.

Factor	All cattle	Young and mature bulls	Cows	Steers	Calves
Total number	998	585	306	58	49
SQR0 (%)	84.1	79.6	90.1	93.1	89.7
Confidence intervals	0.81–0.86	0.76–0.82	0.86–0.93	0.83–0.98	0.78–0.96
SQR1 (%)	3.3	3.5	2.9	1.7	4.0
Confidence intervals	0.02–0.46	0.02–0.05	0.01–0.05	0–0.09	0–0.13
SQR2 (%)	7.7	10.0	4.5	5.1	2.0
Confidence intervals	0.06–0.09	0.07–0.12	0.02–0.07	0.01–0.14	0–0.10
SQR3 (%)	4.8	6.9	2.2	0	4.0
Confidence intervals	0.03–0.06	0.04–0.09	0–0.04	–	0–0.13
Inadequately stunned (SQR2 or SQR3) (%)	12.5	16.7	6.8	5.1	6.1
Confidence intervals	0.11–0.15	0.14–0.2	0.04–0.1	0.01–0.14	0.01–0.17
Inaccurately shot (%)	8.0	8.5	7.1	3.4	14.0
Confidence intervals	0.06–0.1	0.06–0.11	0.05–0.11	0–0.12	0.06–0.27
Re-shot (%)	12.4	16.7	6.5	5.1	6.1
Accurately shot but inadequately stunned (%)	10.4	13.6	4.2	3.4	2.0

and calf). To analyse the proportions of the different levels of stun quality in more detail, a proportional odds model was used (Agresti 2007) where cattle class (young bull, mature bull, cow, steer, and calf) and breed (dairy or beef) were included as fixed factors.

Results

There were no cattle stuck within 60 s. The average stick time was 105 (± 16.5) s, the fastest, 70 s (only two animals), and the longest, 294 s, when an animal fell off the stun crate. The majority of animals (89%) were stuck between 84 and 125 s. The average stick time of cattle shot once (103 [± 13.7] s) was shorter ($P < 0.0001$) than those re-shot (116 [± 27.4] s). Technical design constraints in the sticking area were the main causes for delays in sticking (ie large cattle being stuck in the delivery gate after stunning; cattle rolling off the stun crate requiring a separate pulley to get them back on to the shackle line and derailing of carcases when rounding a bend in the shackle line).

Stun quality

Of 998 cattle, 84.1% were adequately stunned (SQR0). Inadequate stunning occurred in 12.5% of cattle (7.7% with symptoms rated SQR2 and 4.8% with SQR3). Uncertain stun quality (SQR1) was observed in 3.3% of cattle (Table 2). Ninety-eight of 585 (16.7%) bulls (young and mature) were inadequately stunned compared with 27 of 413 (6.5%) other cattle (cows, steers and calves) ($P < 0.0001$). Bulls (both young and mature) showed the high risk symptoms (SQR3) more frequently ($P = 0.0011$) than other cattle (6.9 compared to 2.1%) (Table 2).

Inadequately stunned cattle showed more than one symptom from the stun quality protocol in 53% of cases. Blinking was the most frequently observed SQR3 symptom in bulls (3.5%), while the most frequent in other cattle classes was failure to collapse (1.2%). Full eyeball rotation (SQR2), was the most frequently observed symptom in total, and was present in 11.9% of bulls and 1.9% of other cattle. Nystagmus (SQR2) occurred in 3.3% of bulls and 1.9% other cattle (Table 3). Three of the SQR1 symptoms — gasping, ears up and tongue up in the mouth at sticking — showed significant Kendall's tau correlative values with the presence of inadequate stun symptoms (respectively, 0.33, $P < 0.0001$; 0.31, $P < 0.0001$; and 0.30, $P < 0.0001$). The odds of receiving worse stun quality were significantly increased for bulls, compared with cows (2.3), or beef bulls compared with dairy bulls (2.1). Of the cattle inadequately stunned, 6% first displayed symptoms in the stun box, 57% on the delivery table, 13% on the shackle line, and 24% during sticking procedures.

Shot accuracy and repeat shots

A total of 124 cattle (12.5%) were re-shot. Bulls were re-shot most frequently (16.7%) compared with other cattle classes (6.2%). Inaccurate shooting occurred in 8.0% of all cattle: 8.5% of bulls, 7.1% of cows, 3.4% of steers and 14.0% of calves (see Table 2). Six percent of cattle were shot above, 1.8% were shot beside and 0.2% below, the 'A' area on the skull (Figure 2). In total, 10.4% cattle shot accurately were inadequately stunned. Cattle shot inaccurately were inadequately stunned in 35.0% of cases. Despite being

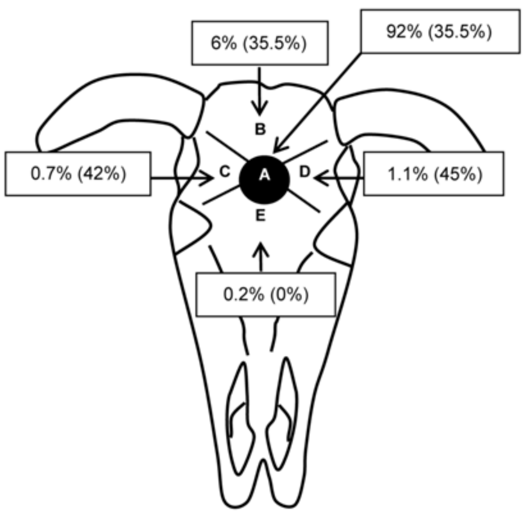
Table 3 Percentage of cattle displaying certain symptoms.

Stun Quality Rate (SQR)	Symptom	Bulls (n = 585)	Cows (n = 306)	Steers (n = 58)	Calves (n = 49)	Total (n = 998)	% seen with other inadequate stun symptoms	Kendall's tau correlations occurring with other inadequate stun symptoms
3	Failed to collapse	1.0	0.9	0	4.0	1.1	18*	0.28
3	Attempt to regain posture	0.2	0	0	0	0.1	100	0.08
3	Vocalisation	0.5	0.3	0	0	0.3	100	0.14
3	Pain reflex	0	0	0	0	0	0	–
3	Blinking	3.5	0.7	0	0	2.2	87	0.39
3	Corneal reflex	1.4	0	0	0	0.8	100	0.23
3	Rhythmic breathing	2.0	0.3	0	0	1.3	86	0.30
2	Full eyeball rotation	11.9	1.9	1.7	0	7.6	30	0.73
2	Nystagmus	3.3	1.6	3.5	2.0	2.7	30	0.44
1	Partial eyeball rotation	1.3	0.9	0	0	1.1	77	0.18
1	Gasping	4.1	1.6	0	0	2.9	72	0.33
1	No tonic phase	0.7	0	0	0	0.4	75	0.12
1	Head raising	0.3	0.3	0	0	0.3	67	0.09
1	Groaning	1.0	0.3	0	0	0.7	72	0.18
1	Reactions to sticking	4.4	5.2	6.9	2.0	4.7	32	0.11
1	Ears up	1.9	1.3	1.7	0	1.6	94	0.31
1	Tongue up in mouth	2.9	2.2	1.7	2.0	2.3	76	0.28

* Cattle could not be tested for reflexes because of no access into the stun box.

shot accurately, 13.6% of all bulls showed symptoms of inadequate stunning, compared with 3.8% of the total number of cows, steers and calves. Of 26 mature bulls, eleven were inadequately stunned and re-shot and nine showed symptoms of inadequate stunning even though accurately shot (eight Holstein Friesian and one Limousin). In total, 14 bulls were shot more than three times and one (a Holstein) was shot five times. No cows, steers or calves were shot more than twice. Beef bulls more frequently displayed the higher risk level for animal welfare (SQR3) compared to dairy bulls (Table 4). During the five-day study period, the highest percentage of cattle found inadequately stunned was 22% bulls compared to 8% of other classes on day 3 (Figure 3). The accuracy of shooting between the five different shooters ranged from 81 to 95% of cattle shot in the optimal area. One shooter (shooter 3) had only worked a few months at the abattoir and shot inaccurately the most frequently, compared to the other shooters who all had at least three years' experience. Shooter 5 had 15 years' experience, and also had the least number of inaccurate shots and inadequate stuns (Table 5).

Figure 2

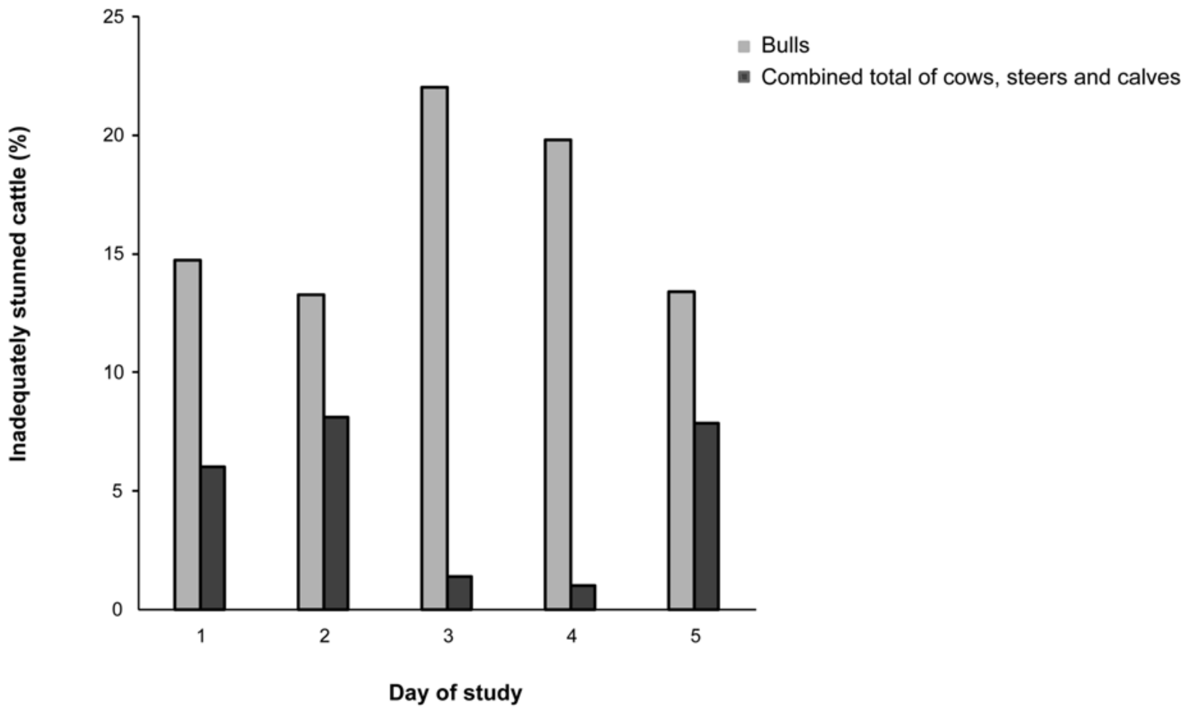


The percentage of cattle shot in the different areas and percent of those shots resulting in inadequate stunning (in brackets). Shots located in the A area are accurate shots and inaccurate shots located in areas B, C, D and E.

Table 4 Differences in stun quality, re-shots and shot accuracy and incidence of inadequate stunning in dairy and beef bulls and young bulls or mature bulls (n = 585).

Factor	Dairy bulls	Beef bulls	Young bulls	Mature bulls (> 30 months)
Total number	493	92	559	26
Inadequate stun (%)	27.9	15.2	15.5	42.3
SQR2 (%)	8.5	18.4	9.1	30.7
SQR3 (%)	5.6	11.9	6.4	11.5
Re-shot (%)	27.1	53.2	15.5	42.3
Accurate shot but inadequate stun (%)	11.5	21.7	12.1	34.6

Figure 3



Daily percentages of inadequately stunned bulls, compared to the combined total of cows, steers and calves.

Table 5 Number and percentage of cattle accurately shot by each shooter during the study.

Shooter ID	Total cattle shot	Accurate shots (%)	Employment period shooter worked at abattoir
1	200	90	5 years
2	240	94	5 years
3	39	81	3 months
4	223	90	3 years
5	296	95	15 years

Discussion

Sticking in cattle after captive-bolt stunning is required to ensure death supervenes. Until recently, Swedish regulations required that sticking should occur within 60 s after stunning to minimise recovery risk (SJVF 2008). Since new EU regulations came into force in 2013, specifying only that sticking should be started as quickly as possible (EC 2009), the 60 s requirement is a now just recommended standard operation procedure. In this study, no cattle were stuck within 60 s after stunning, and the majority of stick times were between 85 and 125 s. Time was required to fix both front legs of the cattle to prevent workers from being kicked during sticking. The proportion of cattle identified as inadequately stunned was considered high, particularly in bulls, which were three times more likely to be inadequately stunned compared with other cattle classes. Similar results have been reported by Gregory *et al* (2007). When cattle do not show clear signs of deep unconsciousness, it is difficult to ascertain if or when pain or fear perception ceases or returns under practical working conditions in an abattoir. 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 is insensible (Gasquoine 1997). Gasping (SQR1), for example, can be associated with cerebral ischaemia just prior to death, but also when the animal is about to recover (Newhook & Blackmore 1982; Blackmore *et al* 1983). Full eyeball rotation (SQR2) was the most frequently seen symptom but in more than half the cases no other symptoms were observed. In fact, cattle with SQR2 symptoms showed no other symptoms in 70% of cases compared to only 27% cattle with SQR3 symptoms, substantiating that it was likely to be a less serious risk to animal welfare than the SQR3 symptoms. Death of a complex organism usually occurs in stages, as tissues progressively cease to function (Newhook & Blackmore 1982). This appeared to be the case in five bulls, where the eyeball fully rotated immediately after stunning, but after 30 s it rolled back centrally, the pupil dilated and all signs of deep stunning ensued. It was standard procedure to cut the skin from the jowls to the sternum prior to chest sticking, and this procedure appeared to stimulate excessive struggling movements in twenty-six (3%) cattle, of which ten cattle displayed further signs of inadequate stunning (ie eye movements and gasping). In these cases it was difficult to ascertain if the excessive reactions were due to unconscious nociceptive arc-reflexes or in fact some form of pain reaction. According to Gregory and Shaw (2000) only part of the brain stem controlling the corneal reflex might be damaged during captive-bolt stunning, resulting in this symptom being absent but other brain stem functions, ie rhythmic breathing, still being present. Rhythmic breathing and corneal reflex were rated SQR3 due to the risk being considered too high for rapid recovery (Gregory 1998). This seemed appropriate as 11 of 12 cattle with rhythmic breathing and all eight cattle with corneal reflex showed other signs of inadequate stunning. Gasping and ears facing backwards at sticking (SQR1) had significant correlative values to the occurrence of inadequate stun symptoms, suggesting the validity of including them in the SQP and motivating closer inspection and testing for responses on cattle with these signs. In an attempt to give a more accurate indication of the level of concern for animal welfare, the stun quality protocol differentiated cattle with obvious signs of deep unconsciousness (SQR0; no risk to animal welfare), to those at risk of recovering consciousness (SQR2; moderate risk to welfare), to those indicating some level of consciousness (SQR3; highest risk to welfare). Providing data showing the percentage of animals within these separate risk levels may be useful for comparative purposes between abattoirs and provide an additional tool when calculating animal welfare risk levels in abattoirs during quality control procedures.

The incidence of inaccurate shots in this study was 8.0%, compared with 51% reported by Gallo *et al* (2003), 7.8% by Fries *et al* (2012) and 35% by von Wenzlawowicz *et al* (2012) where no neck restraints were used. Most cattle that were inaccurately shot were shot high on the head, and Gregory *et al* (2007) reported similar findings. The number of bulls in total that required re-shooting (16.7%) was double that reported by Gregory *et al* (2007). Of the bulls showing inadequate stun symptoms, 79% were, in fact, shot accurately. It was also unexpected to find that only 35% of the inaccurately shot cattle were inadequately stunned, and 10% of the accurately shot cattle inadequately stunned. To maximise brain stem damage, Gilliam *et al* (2012) suggests a higher optimum shot location than in this study. Yet, of the cattle inaccurately shot and inadequately stunned, 70% were shot higher than in the optimal area recommended by EFSA (2004) and almost all were bulls (16 young bulls, three cows, and two calves). However, only the location of the shot on the skull was assessed in this study, and not the angle or penetration depth of the bolt. If the gun was not placed completely perpendicular against the animal's head at the moment of stunning, the penetration depth and impact velocity of the bolt could have been reduced, contributing to a reduced stun effect. Resizable stun boxes and neck restraints could reduce such problems occurring. All cattle with symptoms rated SQR2 or SQR3 were immediately re-shot, indicating that the assessors and abattoir staff concurred as to what constituted inferior stun quality. Re-shooting was performed quickly in those animals judged as inadequately stunned but due to a continued display of symptoms, 15 bulls were shot more than twice. All of these were mature cull bulls (eleven Holsteins, three Charolais and one Hereford). Re-shooting may have a diminutive effect because of a reduction in impact energy due to absorption by fractures in the skull (Adams & Sheridan 2008), or because of an already reduced cranial pressure existing from the previous shot holes. Older bulls tend to have a thicker bone mass on the forehead than other cattle classes, increasing resistance to the kinetic energy delivered by the bolt. This could have been a major contributing factor to the reduced stun quality in bulls compared to other cattle classes. Using more powerful stunners (ie 0.25 calibre matched with suitable cartridge strengths), should reduce the risk of inadequate stuns occurring. Gouveia *et al* (2009) reported that 50% of bulls older than 30 months showed signs of recovery after stunning with a 0.22 calibre captive bolt, also contributing the difficulties in stunning to the thicker frontal skull of old cattle compared with young cattle.

Most of the bulls in this study were between 20 to 24 months old and stunned in delivered consignments. The constant firing into the skulls of bulls may have reduced the gun efficiency. This is supported by the fact that a device for measuring gun power registered that the guns were operating at full capacity when inspected after gun servicing, yet 11% of bulls the following day were inadequately stunned even though shot accurately. There also appeared to be a pattern: when more than ten bulls were shot one after the other, the cases of inadequate stun quality increased until cows were shot. It seemed the weapon was somewhat rested or 'cooled down' when shooting smaller cattle, perhaps due to the use of a lower ammunition charge.

On the third day of the study, many bulls were inadequately stunned during the morning shift. An inspection of the weapon during a break revealed damage to the outer rim edge at the tip of the penetrating bolt. It was suggested the weapon be serviced before stunning recommenced, which resulted in fewer inadequate stuns (3 compared with 19% before the break). This highlights the importance of checking weapons if many animals show inadequate stun symptoms. The least experienced shooter had worked only a couple of months in the abattoir and seemed fearful of the cattle, often hesitating just before shooting. This appeared to disturb the cattle, causing them to become unsettled and evade his approach, which probably contributed to the higher frequency of inaccurate shooting compared with the more experienced shooters.

In order to complete a comprehensive and accurate assessment of animal welfare at stunning, many factors within the slaughter process need considering which require a suitable competence from the assessor and time commitment (at least one day in an abattoir with a daily processing rate of 200 cattle). The stun quality protocol developed in this study provided a valuable tool for assisting in the stun quality evaluations, especially as many symptoms in cattle were observed.

Animal welfare implications and conclusion

The protocol used in this study to assess stun quality was feasible. By classifying the different levels of stun quality, it was possible to see that bulls were at a greater risk for inferior animal welfare than cows, heifers or steers. Beef bulls and older cull bulls were also more likely to show a higher risk level for inferior stun quality than dairy, female or steer cattle classes. Alternating between several weapons when shooting consignments of bulls, using higher calibre weapons (> 0.22 calibre), the use of head restraints, and shorter stun to stick intervals, may optimise stun quality in abattoirs such as this. Proper cleaning and service of guns at least after each day of slaughter should be a mandatory procedure, and in the event that episodes of inadequate stunning occur, the weapon should be replaced with a properly serviced one. The symptoms identified in the stun quality protocol and the relevant risk ratings seemed appropriate for this stun method and species. While cattle should be constantly monitored by the internal staff, this study highlights the importance of external stun quality audits, which can provide further quality control to ensure certain standards of animal welfare are met. Animals should also be continually monitored for stun quality until sticking is complete. The use of protocols, such as developed in this study, can help standardise assessments and allow for benchmarking of stun quality at commercial slaughter. This could contribute to setting minimal standards as a safeguard to animal welfare at stunning.

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