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Assessment of stun quality after gunshot used on cattle: a pilot study on effects of diverse ammunition on physical signs displayed after the shot, brain tissue damage and brain haemorrhages

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Abstract

Moving the slaughter process from the abattoir to the animals' familiar environment has the potential to reduce pre-mortal stressors to a minimum and contribute considerably to improved animal welfare at slaughter. On-farm stunning and killing of free-range cattle via gunshot became legal in Germany in November 2011, including for commercial sale of the meat. As an effective stun is essential for maintaining animal welfare until the animal dies, the goal of this study was to assess the feasibility of delivering an instantaneous and deep stun by an accurate frontal gunshot at cattle. Thirty free-range cattle (Galloway, German Angus) were shot with five different combinations of rifles and bullets. A stun-quality protocol was developed to assess musculoskeletal, optical and respiratory signs displayed after the shot. Key signs, such as failure to collapse, corneal reflex, spontaneous blinking, eyeball rotation or eyeball movement, distinct vocalisation and rhythmic breathing were not evident in 29 of the 30 cattle. Dissections of the heads were used to detect penetration depth of the projectile as well as evaluate brain tissue damage and brain haemorrhage caused by the shot. Tissue damage was marginal and not related to the ascertained level of stun quality. Brain haemorrhages assumed to be sufficient for causing a deep stun were detected in 25 out of 30 cattle. Accurate shot placement turned out to be more important than the application of a certain calibre. However, it was considered crucial for safety reasons that the projectile should remain within the cranial cavity. As long as there are high levels of accuracy, gunshot was considered to be an effective stunning method with the potential of maintaining high standards of animal welfare until death occurs.

Keywords: *animal welfare, brain haemorrhage, cattle, gunshot, physical signs, stun quality*

Introduction

In response to societal as well as scientific demands, animal welfare at commercial slaughter has improved over recent decades, but remains a matter of concern in many places. Psychological and physical pre-mortal stressors still occur in cattle during loading or transport as well as at the abattoir itself (Grandin 1998a, 2006, 2012; Terlouw *et al* 2012; Atkinson *et al* 2013). Frequently, transport-related bruises and lacerations lead to carcase downgrading. Each year, significant losses to the meat industry are caused by stress-induced dark-firm-dry (DFD) meat (Jarvis *et al* 1996; Ferguson & Warner 2008; Algers *et al* 2009; Shen *et al* 2009).

Pre-slaughter stunning via captive-bolt gun is the most common method at commercial cattle abattoirs (Algers & Atkinson 2007; Troeger & Moje 2012) and many slaughter-related studies focus on efficiency and/or optimal shot placement of captive-bolt guns (Lambooy & Spanjaard 1981; Ilgert 1985; Daly *et al* 1987; Finnie 1993a; Grandin 2002; Gregory *et al* 2007; Gouveia *et al* 2009; Kohlen 2011; Gilliam *et al* 2012; Atkinson *et al* 2013). Depending on the size of the animal, captive-bolt guns are usually operated with energies between 300 and 600 J and a relatively low speed of < 100 m s^{-1} for stunning cattle (Algers & Atkinson 2007; Anil & Lambooij 2009). The technical design of stun-related slaughterhouse facilities and stunning devices varies considerably. Service-related problems with the stunning apparatus (unclean devices, worn out parts, use of damp ammunition) are still common, despite the fact they require to be regularly well serviced to ensure a proper stunning (Atkinson *et al* 2013). A lack of shooting accuracy, due to unrestrained animals or disability or fatigue of the shooter, can lead to failed shots or poor stun quality (Grandin 1998a). A field study at German, Swiss and Austrian abattoirs revealed that the overall number of cattle improperly stunned via a captive-bolt gun was approximately 9% (von Wenzlawowicz *et al* 2012), while a Swedish investigation found 12.5% of the cattle insufficiently stunned, of which 16.7% were bulls compared to 6.5% other cattle (Atkinson *et al* 2013). Gregory *et al* (2007) reported a higher prevalence of poorly stunned bulls (14.0–16.3%) compared to steers (5.2–7.4%) and heifers (4.7–6.1%). Even wellequipped abattoirs, which use highly efficient pneumatic stun guns, in terms of kinetic energy transfer, and which use head and neck restraint devices where the possibility of failure shots is approximately zero (Troeger & Moje 2012), repeatedly report a practical dilemma. On the one hand, shot accuracy and stun quality are improved but, on the other, the restraint system may result in severe stress to the animals (Ewbank *et al* 1992; Grandin 1992; Atkinson & Algers 2009; Troeger & Moje 2012).

For the assessment of stun quality generated by captive bolt, several protocols focusing on musculoskeletal, optical and respiratory signs have been developed (Grandin 2002; EFSA 2004; Gregory *et al* 2007; Atkinson *et al* 2013; bsi 2013). Rating of these factors resulted in categorisation into, for example, 'deep/good', 'poor' or 'undefined' stun-quality levels (Atkinson & Algers 2007).

In addition to stun-quality protocols, macroscopic cranial examinations provide insight into the efficiency of the stun. The brainstem (truncus encephali, consisting of medulla oblongata, pons, mesencephalon) is considered the most crucial target area, as serious destruction, especially of the medulla oblongata, is likely to cause unconsciousness or death by respiratory arrest (Gregory & Shaw 2000; Algers & Atkinson 2007; König & Liebich 2008). Additionally, the increase of intra-cranial pressure that occurs following haemorrhage and oedema affects brainstem functions (Gregory & Shaw 2000). However, structural changes in the brain following a mechanical stun have been rarely investigated (Finnie *et al* 2002). A number of investigations have shown that the use of commonly used cartridge-fired captive-bolt guns does not always produce an effective stun. Algers and Atkinson (2007) examined the percentage of brain surface with blood haemorrhage in cattle stunned by a cartridge-fired captive-bolt gun and a more powerful pneumatic gun, using pneumatic power for bolt firing. The pneumatically operated gun caused heavier bleeds at the back of the brain and was considered to be favourable for stunning large bulls. Finnie (1993a,b) compared brain damage in sheep caused by free-bullets from a gun to brain damage caused by a captive-bolt gun. The damage caused by a captive-bolt gun was much less severe. A main reason for the difference was, probably, the temporary cavitation effect (also described by Di Maio 1999): due to the free bullet's much greater velocity, it imparts higher radial forces to the surrounding tissue and forms a comparatively large temporary cavity. While this cavity exists only for microseconds, it determines the permanent wound track (Di Maio 1999). Finnie (1993b, 1997) described widely spread stretch injuries to neural elements and blood vessels, which were caused by the temporary cavitation effect and increased the stun efficiency. Furthermore, fragments of a free bullet cause additional secondary wound tracks, helping to achieve a proper stun.

Stunning failures, however, are not solely due to the technical devices. Cattle behaviour can also have a significant effect. Gregory *et al* (2007) reported a significantly higher prevalence of poorly stunned cattle in aroused (19%) versus non-aroused (8%) cattle, independent of shooting accuracy. Consequently, free-ranged beef cattle may be at a greater risk of stunning failures. These animals are usually not as well accustomed to human contact and respond more excitably to handling procedures on the day of slaughter (Bunzel-Drueke *et al* 2009). A possible way to reduce premortal stress experienced by these animals is to shift the first steps of the slaughter process from the abattoir to the animals' familiar, on-farm, environment. To meet veterinary and food safety issues, ante mortem live inspection of the animals and a high standard of hygiene must be provided. Subsequently, carcases can be transported to the abattoir, where evisceration, inspection of carcases and organs as well as further processing will take place. Stunning and killing on-farm via gunshot could be a means of minimising premortal stress, especially in shy cattle (AVMA 2013; Schiffer *et al* 2013). However, there is not sufficient practical experience (in Europe) nor are there scientific recommendations, such as those available for captive-bolt stunning.

Within the EU, the current legal requirements affect on-farm gunshot for slaughter purposes adversely. In regulation (EC) No 1099/2009 (EC 2009) on the protection of animals at the time of killing, the gunshot is listed as an allowable stunning method (Annex I, Chapter I, Table I). However, regulation (EC) No 853/2004 (EC 2004) on the hygiene of foodstuffs (Annex III, Section I, Chapter IV, 2b) states that only live animals may enter a slaughter plant. Only in Germany has shooting on-farm become a legal stunning and killing method for all-season outdoor cattle. In November 2011, the German Government passed an amendment (BMJ 2007/2011, Tier-LMHV, §12, Section 3) that permits on-farm slaughter of particular free-range cattle as long as transport time from farm to slaughter facility does not exceed 1 h and permission by the responsible regional public authority is granted. Consequently, on-farm slaughter via gunshot has become a legal stunning and killing method in all situations rather than one restricted to emergency cases only. However, no further statutory regulations concerning this method, such as those for shooting of farmed game (BMJ 2012), were available at this time.

The goal of this project was to evaluate the potential of on-farm slaughter of free-range cattle via gunshot as a professional, reliable and easily controllable on-farm slaughter method. With respect to animal welfare, a deep stun, that caused instantaneous unconsciousness and insensibility, lasting until the animal has died through loss of blood, is essential. Therefore, in this study, the feasibility of provoking a deep stun by a frontal gunshot in slaughter cattle was assessed. The following questions were addressed:

- Did any of the tested calibres affect the animal sufficiently for physical signs to indicate a deep stun?
- Did any of the tested calibres cause severe brain tissue damage?
- Did any of the tested calibres cause brain haemorrhages classified as sufficient?

In situ as well as back-up video monitoring of the shooting procedure were used to address the first point while head dissections addressed the second and third points. Based on the results of all three the relationship between brain tissue damage, brain haemorrhage, and the associated physical signs were examined.

Materials and methods

Study animals and experimental set-up

The cattle originated from two farms keeping all-season outdoor cattle (Galloway and German Angus) in Northern Germany. The carcases of the cattle were intended for commercial sale. Therefore, timing of the study depended on the co-operating farmers' herd management as well as their marketing activities. Data were collected from Galloway (n = 25) and German Angus (n = 5) breeds of cattle. The German Angus cattle were bulls and Galloways were a mixture of steers (n = 22) and females (n = 3). The median age was 29 months and the median carcase weight was 230 kg. The data were evaluated descriptively as well as in bivariate analyses with crosstabs.

Of the total animals slaughtered during this study, nine were shot following the intended protocol, where the shot occurred within an enclosure ('paddock'; Figure 1) that was familiar to the animals. In order to accustom the animals to this 10 × 10 m shooting paddock, a group of ready-for-slaughter cattle was placed *in situ*, several weeks prior to slaughter. These animals had continuous access to stable, paddock and pasture land. For organisational reasons, three additional set-ups, besides the intended one, were employed: i) eight animals were shot on their ordinary pasture; ii) five were shot within an enclosure, but without prior habituation to this place; and iii) eight were shot within a wooden shed that was familiar to the animals.

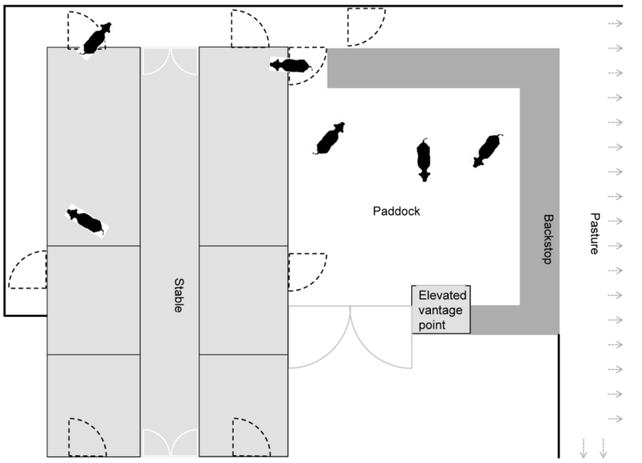
Ammunition

The different calibres and types of ammunition (Table 1) were chosen based on previous findings from a study evaluating the effects of diverse ammunition on post mortem isolated cattle heads (Schiffer *et al* 2014) and on experiences of marksmen accredited by German hunting legislation, who had already slaughtered outdoor cattle via gunshot in Germany. Two small bores (.22 Magnum) and three large bores (8×57 JS, 7×64, .30-06) were used. One of the large bores (7×64) had a reduced velocity and energy due to the application of a silencer. For organisational reasons, the .30-06 variation was only used on the German Angus.

Shooting

In addition to approval from the University animal protection official, the studies were performed after thorough assessment and permission by the responsible regulatory and veterinary state authorities. The latter were occasionally present during the shooting sessions. Frontal gunshot was performed for all cattle in the current study, with the assumed optimal shot placement as described previously (Schiffer *et al* 2014), even following present recommendations (Kohlen 2011) regarding shot placement for captive-bolt stunning. The animals were shot at a range of 2.5–20 m with negligible differences in the efficacy of the projectile (velocity, energy) within this relatively short range expected. In order to render precision shooting possible, ballistics were taken into consideration for each setting and a control shot fired before any animal was shot. The shooter, employing a long rifle as a weapon, was situated at an elevated vantage point, approximately 2 m above the ground (Figure 2). For technical reasons, six out of the 30 cattle were shot from the ground instead of from a point of elevation. In all cases, conspecifics were around in order to enhance calmness of the group as well as to provide free choice for the shooter. Thus, all animals in the group needed live inspection by the responsible state veterinarian within 24 h pre-slaughter. After evaluating the physical signs, the shot animal was hoisted by a front loader and immediately exsanguinated in order to decrease the risk of regaining consciousness and sensibility to pain. The stun-to-stick interval was measured as an indicator for promptness of exsanguination. For evisceration and further processing, the dead animal was transported to the local abattoir. The blood was collected and disposed of at the abattoir. The following contingency procedures were put in place: in the event of a misplaced shot without a collapse of the animal, the animal was to be shot a second time by the rifle; if the stun quality emerged as poor between collapse of the animal and exsanguination, a captive-bolt gun should be deployed as a back-up stunning device; and the captive-bolt gun should be kept adequately maintained and constantly ready at hand.

Figure 1



Top view on the preferred setting for the gunshot method.

Physical signs indicating a deep stun

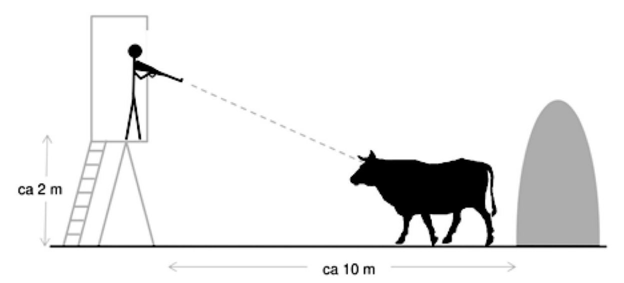
A stun-quality protocol was compiled for the assessment of musculoskeletal, optical and respiratory signs after the gunshot (Table 2). Each of the signs was monitored both directly after the shot and, retrospectively, via video evaluation and rated from 1 (best) to 3 (worst). The stun-quality protocol is based on stun-quality assessment as carried out after captive-bolt stunning (Atkinson & Algers 2007, 2009; Gregory *et al* 2007; Grandin 2012; bsi 2013). In order to gain more detailed information, the sign 'kicking and reaction to sticking procedures' (Atkinson & Algers 2007) was separated into four aspects which were 'muscle spasms of legs after collapse', 'muscle spasms of legs during transport' (while muscles are exposed to tractive forces when hoisted by the front loader),

Table 1 Ammunition characteristics and numbers of cattle (n) shot per calibre.

Calibre	Designation/Manufacturer#	Type of projectile	Diameter (mm)	Mass (g)	V_0 (m s^{-1})*	E_0 (J)*	n
8×57†	JS, ID Classic, RWS/RUAG Ammotec GmbH, Fürth, Germany	Semi-jacketed, part fragmentating	8.2	12.8	800	4,096	5
7×64†	Subsonic**/Samereier Reduzierhülsen/Fa Johann Samereier, Bayerbach, Germany	Full metal jacketed	7.2	10.3	315	481	3
.30-06‡	Bionic yellow, RWS/RUAG Ammotec GmbH, Fürth, Germany	Homogeneous, lead-free, part fragmentating	7.6	10.0	885	3,915	5
.22§	Winchester Magnum Rimfire/Frankonia Handels GmbH & Co KG, Rottendorf, Germany	Full metal jacketed	5.6	2.6	580	440	4
.22§	Winchester Magnum Rimfire/Frankonia Handels GmbH & Co KG, Rottendorf, Germany	Semi-jacketed, part fragmentating	5.6	2.6	580	440	13
Total							**30**

* V_0 and E_0 describe the velocity/energy of the projectile at the muzzle (according to the producers/resellers, no exact values).
** A silencer was employed for these shots.
† Diameter (mm) times length of the projectile (mm);
‡ Diameter (inches) of the projectile combined with the year of adoption of this projectile (Di Maio 1999);
§ Diameter (inches) of the projectile;
# For further information about ammunition and its designations see, for example, Di Maio (1999), wikipedia, https://en.wikipedia.org/wiki/Bullet, or the glossary of SAAMI (Sporting Arms and Ammunition Manufacturers` Institute Inc, Connecticut) at http://www.saami.org/specifications_and_information/index.cfm.

Figure 2



Scheme of the experimental set-up.

'reactions to skin incision' and 'reactions to cutting the main blood vessels' (Table 2, italics).

To determine the level of stun quality, three categories were defined: i) deep stun; ii) poor stun; and iii) ambiguous stun (Table 3). In order to achieve, for example, a 'deep' stun-quality level, five crucial signs needed to be rated '1'. These were 'collapse and typical tonic phase', 'righting reflex during transport', 'eyeball rotation/movement', 'spontaneous blinking' and 'corneal reflex'. All further signs were considered as less alarming in case of single or slight occurrence and, thus, they were also allowed to be rated '2'.

Dissection

Anatomical measures of each head were determined from: i) the length between the crest of the head and the caudal edge of the nose; ii) the length between the medial canthi (inside corners) of the eyes; iii) the length between the inside corner of the eye and the crest of the head; and iv) the length between the inside corner of the eye and the caudal edge of the nose (modified according to Kohlen 2011; Schiffer *et al* 2014). Afterwards, the hide was removed and the position of the entry wound identified by measuring the deviation from the optimal shot placement (Schiffer *et al* 2014). Skull thickness at the bullet hole and the diameter of the bullet hole were determined. The angle of entry was determined by carefully introducing a slim sounding rod into the bullet hole, following the trajectory until the exit hole (if the bullet passed through the skull) or the bullet itself (if it remained within the skull) could be detected. Then the angle was measured by means of an angle measurement protractor. Zero degrees was determined in rostral (nostrils) and 180° in dorsal (crest) direction. A right angle was expected to be ideal (Schiffer *et al* 2014). The depth of penetration of the bullet was also determined at this stage. Subsequently, a square of the skullcap (calvarium) was removed using an electrical saw as well as a rubber mallet and a chisel. Afterwards, the dura mater was taken off. Brain tissue damage and brain haemorrhage, respectively, of the cerebrum, cerebellum, and the ventral side of the brain at the area around the brainstem were identified. After the dissections, all heads were disposed of appropriately.

Brain tissue damage

According to Algers and Atkinson (2007), tissue damage, or bleeding occurring in the frontal regions of the brain are not necessarily related to a deep stun-quality level. This is because the arteries entering the

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Table 2 Protocol for the assessment of stun quality following gunshot at cattle.

Physical sign		Assessment 1	Assessment 2	Assessment 3
Musculoskeletal	Collapse and typical tonic phase	Immediate	No tonic phase	Attempt to get up/no collapse
	Righting reflex during transport*	None	Indistinct	Distinct
	Kicking and reaction to sticking procedures**			
	Muscle spasms of legs after collapse	*None*	*Unco-ordinated*	*Excessive*
	*Muscle spasms of legs during transport**	*None*	*Unco-ordinated*	*Excessive*
	Reaction to skin incision	*None*	*Slight*	*Distinct*
	Reaction to cutting the main vessels	*None/slight*	*Distinct*	*Excessive*
	Tail tonus	Atonic	Indistinct	Distinct
	Ear tonus	Atonic	Indistinct	Distinct
	Tongue	Atonic (protruding)	Not protruding	Stiff curled/co-ordinated movement
Optical	Eyeball rotation/movement	None after a maximum of 20 s	Nystagmus or remaining turned away	Distinct/directed
	Spontaneous blinking	None	Once	Multiple
	Corneal reflex	None	Once	Multiple
Respiratory	Breathing	None	Once (sighing)	Rhythmic
	Vocalisation	None	Once (sighing)	Distinct (gasping, groaning, mooing)

* 'Transport' of the shot animal between place of shooting and place of exsanguination via front loader. This was a few metres and muscles were exposed to tractive forces during hoisting.
** 'Kicking and reaction to sticking procedures' means 'muscle spasms of legs after collapse'/'muscle spasms of legs during transport'/'reaction to skin incision' and 'reaction to cutting the main vessels'.

Table 3 Stun-quality levels associated with the stun-quality protocol.

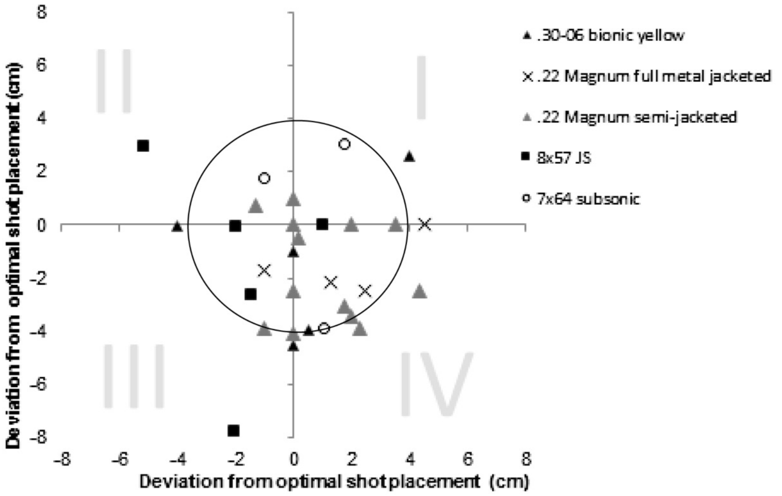
Stun-quality level	Characteristics
Deep	Immediate collapse and typical tonic phase, no righting reflex during transport, no eyeball movement/rotation after a maximum 20 s, no spontaneous blinking, no corneal reflex (ie the rating of these physical signs has to be '1'). No excessive muscle spasms of legs and reaction to sticking procedures, no distinct tail tonus, no distinct ear tonus, tongue without co-ordinated movements and not stiffly curled, no rhythmic breathing, no distinct vocalisation (ie the rating of these physical signs is allowed to be '1' or '2', but not allowed '3')
Poor	As soon as one or more of the following occurs (ie rating '3'): attempt to get up or no collapse, distinct righting reflex during transport, distinct/directed eyeball rotation/movement, multiple spontaneous blinking, multiple corneal reflex, rhythmic breathing, distinct vocalisation
Ambiguous	If the reactions do not clearly fit towards the 'deep' or 'poor' categories

Table 4 Measurements of the cattle heads employed in the study (n = 30).

Factor	Mean (± SD) (cm)	Coefficient of variation (%)
Crest of the head: caudal edge of nose	42.1 (± 3.2)	8
Medial canthi of the eyes	18.9 (± 1.8)	10
Eye: crest of the head	24.5 (± 1.8)	7
Eye: caudal edge of nose	22.7 (± 2.4)	10
Skull thickness at the bullet hole*	1.7 (± 0.7)	41

* For technical reasons, skull thickness was not measured for eight Galloways, therefore n = 22.

Figure 3



Deviation (cm) from the assumed optimal shot placement located at the origin of the co-ordinate system, across all calibres tested in the study (see Table 1).

Table 5 Numbers of cattle related to their stun-quality level and deviation from the optimal shot placement.

		Deviation from optimal shot placement		Total
		< 4 cm	≥ 4 cm	
Stun-quality level	Deep	15	7	22
	Poor	0	1	1
	Ambiguous	2	5	7
Total		**17**	**13**	**30**

brain at its base determine the area around the brainstem as being the most crucial target area in order to cause a proper stun. Thus, this study, focused on the ventral side of the brain and brain tissue damage was defined as 'severe' when there was a complete destruction of the brainstem, and 'marginal' if it was less or if the trajectory of the bullet was the only area providing damaged brain tissue (Schiffer *et al* 2014).

Brain haemorrhage

Extra-axial haemorrhages (ie within the skull but outside of the brain tissue) that occurred on the right and left side of the cerebrum, cerebellum and brainstem were identified. They were classified according to the estimated incidence of bleedings on the brain tissue surface within the categories of 'severe', 'moderate' or 'none'. They were defined as 'sufficient' if classified as 'severe' in the area around the brainstem plus at least 'moderate' at the cerebrum and 'moderate' at the cerebellum. This definition was based on literature establishing that brain haemorrhages tended to occur on the opposite side of the impact ('contre-coup'-effect) and arterial bleedings in the subdural or subarachnoidal region around the brainstem and basal parts of the brain were most crucial for a deep stun (Gregory & Shaw 2000; Algers & Atkinson 2007; König & Liebich 2008).

Results

Sample structure

Differences in head anatomy were marginal (Table 4). Only skull thickness varied more considerably than the other measurements, as established by the coefficient of variation.

Shooting

When converted into a co-ordinate system with the origin designated as the assumed optimal shot placement (Schiffer *et al* 2014), most of the shots (24 out of 30) were located in the third and fourth quadrant, ie on the x-axis or below (Figure 3). In a previous study, shots within a radius of 4 cm from the optimal shot placement caused severe brain tissue damage in post mortem cattle heads (Schiffer *et al* 2014). Even if a smaller target region might be preferable for practical use, 4 cm was used as a 'critical limit' in this investigation also. Seventeen out of 30 shots deviated < 4 cm from the optimal shot placement and 13 deviated ≥ 4 cm (maximum 8 cm) from the optimal shot placement.

Out of 17 shots with a deviation < 4 cm, 15 were associated with a 'deep' stun-quality level and two with an 'ambiguous' stun-quality level (Table 5). Out of 13 shots with a deviation ≥ 4 cm, five were associated with an 'ambiguous' and one with a 'poor' stun-quality level.

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Table 6 Numbers of cattle shot per calibre (see Table 1) with the projectile passing straight through the skull or remaining in the cranial cavity at a certain penetration depth.

Calibre	Passing straight through the skull	Remaining in the cranial cavity	Mean (± SD) penetration depth (cm)	Number of shot cattle in total
8×57 JS	5	0	–	5
7×64 Subsonic	3	0	–	3
.30-06 Bionic yellow	3	2	12.3 (± 3.2)	5
.22 Magnum full metal jacketed	2	2	13.7 (± 2.6)	4
.22 Magnum semi-jacketed	0	13	10.2 (± 2.5)	13

The large-bore calibres 8×57 JS and 7×64 Subsonic, passed straight through the skull in all cases (Table 6). The calibres of .30-06 Bionic yellow (large bore) and .22 Magnum full metal jacketed (small bore) were inconsistent with some, but not all, passing through the skull. The small-bore calibre .22 Magnum semi-jacketed, was the only calibre that always remained at the base of the cranial cavity. The mean penetration depth for this small-bore calibre was 10.2 (± 2.5) cm.

The median angle of impact for all shots was 85°. In four cases, the angle of impact was > 100°. These animals were eating when the shot took place, providing a lowered head and, therefore, a more obtuse angle of impact compared to animals shot whilst upright. The median stun-to-stick interval for all shots was 102 s, which exceeds the 60 s stipulated as maximum stun-to stick interval for cattle (BMJ 2012).

Physical signs indicating a deep stun

The stun-quality protocol (Table 2) was used for assessing the stun quality of each animal, and results were compiled per calibre (Table 7). Overall, 22 shots out of 30 resulted in a 'deep' stun-quality level, one in a 'poor', and seven in an 'ambiguous' stun-quality level. Each of the tested calibres resulted in a minimum of one animal with a 'deep' stun. The only animal with a poor stun-quality level, quantified from a distinct vocalisation, was shot with a full metal jacketed projectile of the .22 Magnum calibre. This shot was not accurate, ie its deviation from the optimal shot placement was ≥ 4 cm. Similarly, five of seven shots with an ambiguous stun-quality level deviated ≥ 4 cm from the optimal shot placement.

The display of musculoskeletal signs rated worse than '1' was the most frequent reason for an animal being categorised as ambiguously stunned. 'Tail tonus' and 'muscle spasms of legs during transport' were those musculoskeletal signs appearing most frequently. Neither 'muscle spasms of legs after collapse' nor 'muscle spasms of legs during transport' were evident in ten of 13 cattle shot with a semi-jacketed projectile of the small-bore calibre .22 Magnum.

Optical signs were never evident, ie were rated best ('1') in any case, and respiratory signs occurred four times with one distinct vocalisation resulting in a poor stun-quality level.

The features typically associated with a 'deep' stun (brain tissue damage and brain haemorrhage will be referred to in the following sections) are pictured in Figure 5.

Figure 4

Recommended angle of impact (*circa* 90°) for a frontal gunshot at cattle.

Brain tissue damage

Only the damage to the tissue of two brains was classified as 'severe' according to the previous definition (see *Materials and methods*). Twenty eight of 30 brains had slightly or not-at-all damaged tissue and the brain tissue damage was classified as 'marginal' (Table 8).

Both of the 'severe' shots came from the 8×57 JS calibre (large bore) and were placed on a horizontal line close to the optimal shot placement (Figures 3 and 6). They resulted in a 'deep' stun-quality level (Table 9). Another shot (.30-06 calibre) located on the same line, but with a greater deviation (4 cm), caused only minimal tissue damage in the left hemisphere of the cerebrum. The associated stun-quality level of this shot was 'ambiguous'. Three further shots with semi-jacketed projectiles fired from the small-bore calibre .22 Magnum, which provides ten times less energy, were in a similar placement as the 8×57 JS shots and caused almost no tissue damage. However, the related stun-quality level was 'deep'.

Three further shots by the large calibre (8×57 JS) caused 'marginal' damage, but they achieved a 'deep' stun-quality level. These contradictory results suggest that brain tissue damage had no influence on the stun quality and was negligible regarding the outcome of this study.

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Table 7 Rating (see Table 2) and frequency of the physical signs displayed after gunshot and the associated stun-quality level, across all calibres (see Table 1).

Physical signs and their rating			Frequency of physical signs (n = number of cattle shot per calibre)					
			8×57 JS (n = 5)	7×64 Subsonic (n = 3)	.30-06 Bionic yellow (n = 5)	.22 Magnum full metal jacketed (n = 4)	.22 Magnum semi-jacketed (n = 13)	Total
Musculoskeletal	Collapse and typical tonic phase	1	5	3	5	4	13	30
		2	–	–	–	–	–	–
		3	–	–	–	–	–	–
	Righting reflex during transport*	1	5	3	3	3	13	27
		2	–	–	2	1	–	3
		3	–	–	–	–	–	–
	Muscle spasms of legs after collapse	1	3	3	2	3	10	21
		2	2	–	2	1	3	8
		3	–	–	1	–	–	1
	*Muscle spasms of legs during transport**	1	–	–	–	4	10	14
		2	4	3	3	–	3	13
		3	1	–	2	–	–	3
	Reaction to skin incision	1	4	1	2	3	7	17
		2	1	1	3	–	6	11
		3	–	1	–	1	–	2
	Reaction to cutting the main vessels	1	1	2	3	3	9	18
		2	3	1	–	–	3	7
		3	1	–	2	1	1	5
	Tail tonus	1	1	1	1	3	6	12
		2	3	1	4	–	6	14
		3	1	1	–	1	1	4
	Ear tonus	1	4	1	4	3	11	23
		2	1	2	1	1	2	7
		3	–	–	–	–	–	–
	Tongue	1	5	2	4	3	7	21
		2	–	1	1	1	6	9
		3	–	–	–	–	–	–
Optical	Eyeball rotation/ movement	1	5	3	5	4	13	30
		2	–	–	–	–	–	–
		3	–	–	–	–	–	–
	Spontaneous blinking	1	5	3	5	4	13	30
		2	–	–	–	–	–	–
		3	–	–	–	–	–	–
	Corneal reflex	1	5	3	5	4	13	30
		2	–	–	–	–	–	–
		3	–	–	–	–	–	–
Respiratory	Breathing	1	5	3	5	4	13	30
		2	–	–	–	–	–	–
		3	–	–	–	–	–	–
	Vocalisation	1	5	3	4	3	11	26
		2	–	–	1	–	2	3
		3	–	–	–	1	–	1
Stun-quality level (according to Table 3)	Deep		4	2	1	3	12	22
	Poor		0	0	0	1**	0	1
	Ambiguous		1	1**	4**	0	1	7

* 'Transport' of the shot animal between place of shooting and place of exsanguination via front loader. This was only a few metres but muscles were exposed to tractive forces during hoisting. ** Deviation from the optimal shot placement ≥ 4 cm.

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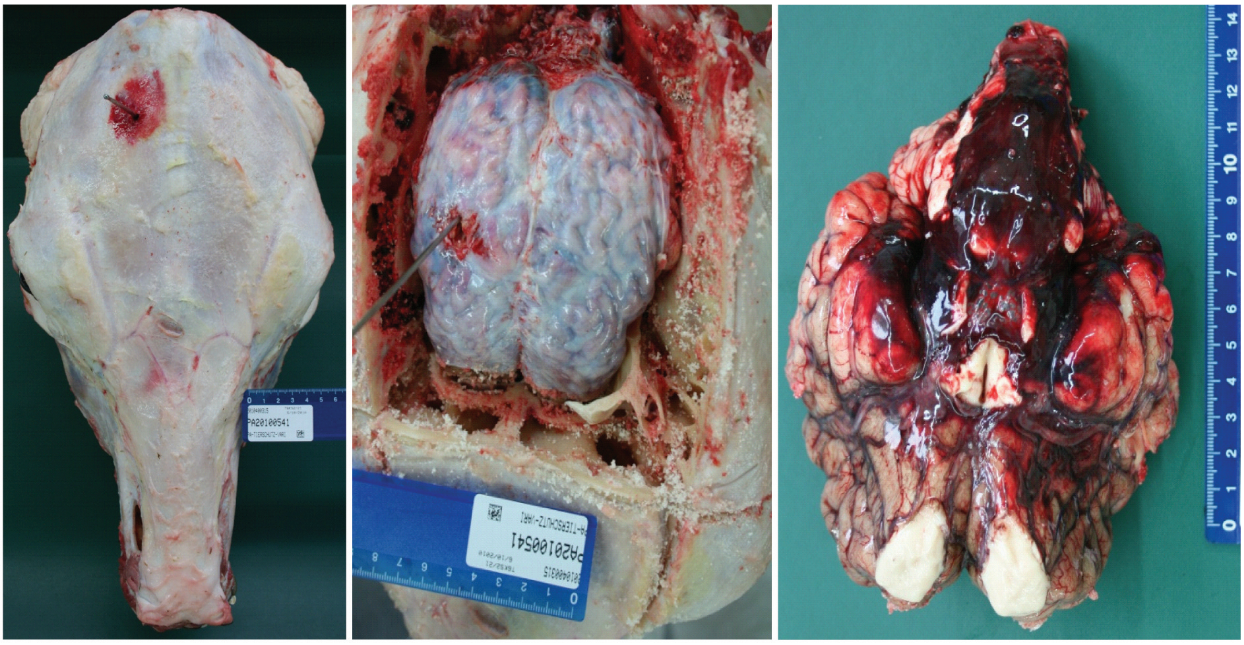
Figure 5



Typical example of an animal that achieved a deep stun-quality level. Images showing (left) tolerable deviation from the optimal shot placement, (middle) the brain tissue remained almost intact except for the trajectory of the projectile and (right) sufficient brain haemorrhages for a deep stun, especially on the ventral side of the brain.

Brain haemorrhage

Twenty-five out of 30 shots caused brain haemorrhages classified as 'sufficient' for a proper stun (Table 10, Figure 7) according to the above definition (see *Materials and methods*). All of the five shots causing haemorrhages classified as 'insufficient' deviated from the optimal shot placement ≥ 4 cm. They inflicted only 'moderate' brain haemorrhages at the brainstem. The classification of haemorrhages in the brain beyond the brainstem (cerebrum and cerebellum) were classified as 'moderate' at a minimum. Haemorrhages classified as 'none' did not occur.

In three out of the five shots with 'insufficient' haemorrhages, the related stun quality was 'ambiguous' and one was 'poor' (Table 11). The other shot with 'insufficient' haemorrhages (8×57 JS) passed beside the brain but still achieved a 'deep' stun quality. In four cases, brain haemorrhages were classified as 'sufficient', but the associated stun quality was classified as 'ambiguous'. This occurred once after an 8×57 JS shot, twice after a .30-06 Bionic yellow shot and once after a .22 Magnum semi-jacketed shot. Three of these shots deviated from the optimal shot placement by ≥ 4 cm.

Table 8 Numbers of cattle shot per calibre (see Table 1) that received severe or marginal brain tissue damage.

Calibre	Brain tissue damage		Total
	Severe*	Marginal*	
8×57 JS	2	3	5
7×64 Subsonic	0	3	3
.30-06 Bionic yellow	0	5	5
.22 Magnum full metal jacketed	0	4	4
.22 Magnum semi-jacketed	0	13	13
Total	**2**	**28**	**30**

* See *Brain tissue damage* in the *Materials and methods*.

Table 9 Numbers of cattle related to their stun-quality level (see Table 3) and brain tissue damage.

		Brain tissue damage		Total
		Severe*	Marginal*	
Stun-quality level	Deep	2	20	22
	Poor	0	1	1
	Ambiguous	0	7	7
Total		2	28	30

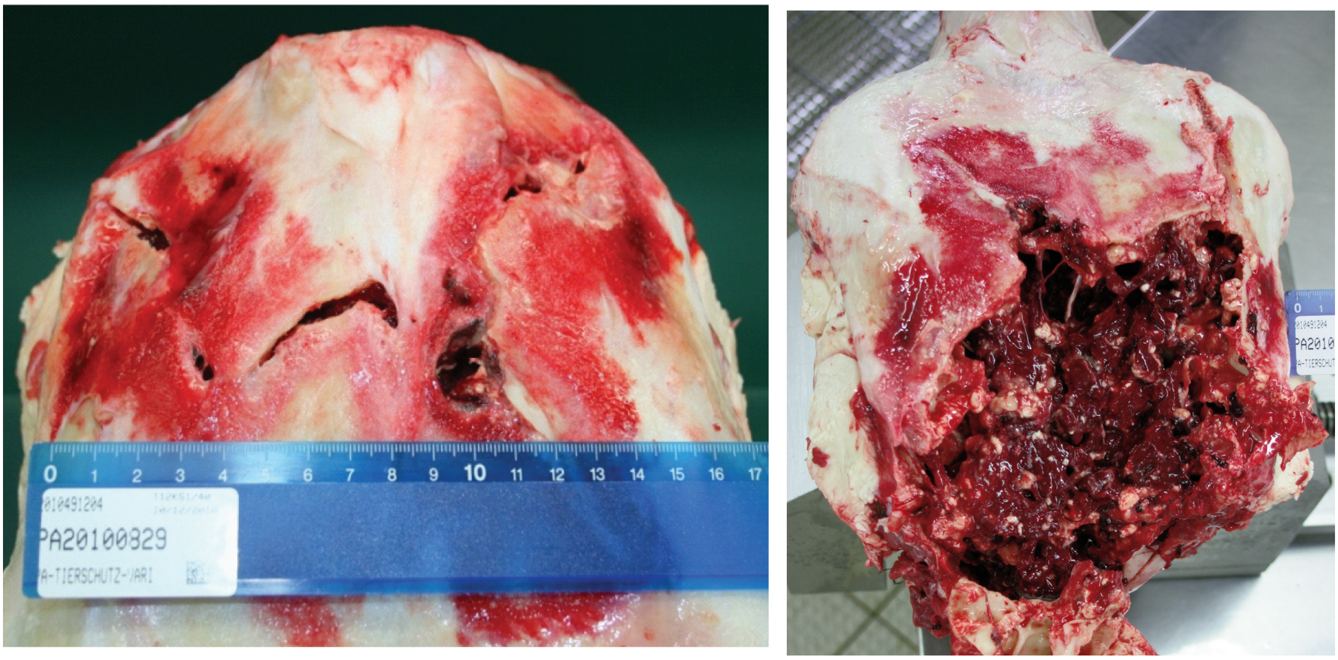
* See *Brain tissue damage* in the *Materials and methods*.

Discussion

Shooting

In a previous study of shots at isolated cattle heads, Schiffer *et al* (2014) found that only shots from the small-bore calibre .22 Magnum, using semi-jacketed projectiles, remained inside the head. This result was confirmed by the present study (Table 6) on live animals. All of the large-bore shots and half of the .22 Magnum full metal jacketed projectiles

Figure 6



Exemplary view on a head shot by a large-bore calibre (8×57 JS). Images show (left) the frontal view, before removal of the skullcap with fracture of the frontal bone above and beside the large entry hole of the bullet and (right) the top view, after removal of the skullcap where the brain tissue was completely destroyed and no ordinary anatomical structures could be detected any longer. Severe bleeding occurred within the whole cavity.

Table 10 Numbers of cattle shot per calibre (see Table 1) that received sufficient or insufficient brain haemorrhages.

Calibre	Brain haemorrhages		Total
	Sufficient*	Insufficient*	
8×57 JS	4	1	5
7×64 Subsonic	2	1	3
.30-06 Bionic yellow	3	2	5
.22 Magnum full metal jacketed	3	1	4
.22 Magnum semi-jacketed	13	0	13
Total	**25**	**5**	**30**

* See *Brain haemorrhages* in the *Materials and methods*.

Table 11 Numbers of cattle related to their stun-quality level (see Table 3) and brain haemorrhages.

		Brain haemorrhages		Total
		Sufficient*	Insufficient*	
Stun-quality level	Deep	21	1	22
	Poor	0	1	1
	Ambiguous	4	3	7
Total		25	5	30

* See *Brain haemorrhages* in the *Materials and methods*.

passed straight through the skull, even though the latter provided the same energy and velocity as the .22 Magnum semi-jacketed projectiles. The .22 Magnum semi-jacketed projectiles remained within the cranium. This can be explained by the different design characteristics of each after hitting the target. The full metal jacketed projectiles were designed to stay solid (no fragmentation), while the semi-jacketed projectiles are intended to partly fragment. Di Maio (1999) established that, in contrast to semi-jacketed bullets, full metal jacketed bullets provided a delayed temporary cavity and, thus, their transfer of kinetic energy is not as rapid as the directly expanding and very efficient semi-jacketed bullets. Moreover, compared to a penetrating captive-bolt pistol, the fragmentation of free bullets and the secondary wound tracks caused by the fragments of the bullet increase the efficiency of the shot (Finnie 1997). Due to the small number of animals used with each calibre, no preferences regarding different types of projectiles and their stun efficiency could be derived in this study. However, all shots using the .22 Magnum semi-jacketed calibre remained within the head, which is highly favourable in terms of both safety and energy transfer. All of their kinetic energy is utilised in wound formation within the cranium and, thus, the temporary cavity is larger compared to ones from projectiles that exit the skull. This is the case even when the exiting projectile possesses a higher kinetic energy than the projectile that remains within the cranium (Di Maio 1999). The mean penetration depth of the shots that remained in the cranium in this study was 10.2 (± 2.5) cm. In such cases, the cranial bone was usually the terminal point for the projectile.

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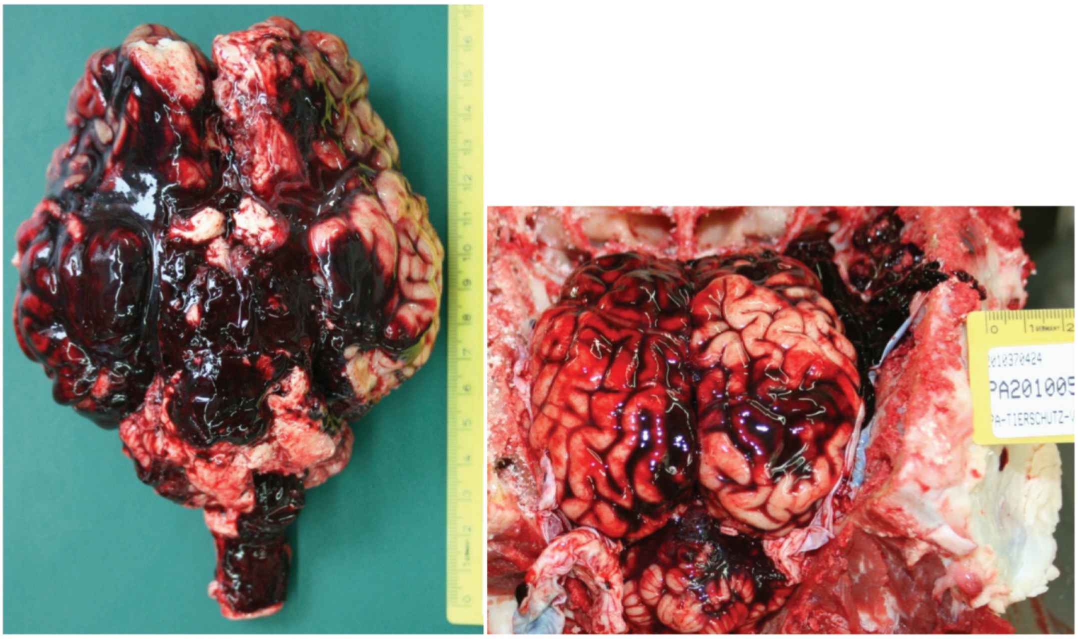
Figure 7



Example of a brain with haemorrhages classified as 'sufficient'. Images show the ventral (left) and dorsal (right) views of the brain.

This penetration length was greater than the length of many commonly employed captive-bolt guns (providing a retractable bolt with a length of 8 cm). Thus, the probability of fatally impacting crucial areas on the ventral side of the brain is increased by employing an accurate gunshot compared to a shot by some ordinary captive-bolt guns. The effect increased even more when a semi-jacketed projectile that remained in the head was utilised.

Shifting the traditional shot placement moderately upwards (Kohlen 2011; Schiffer *et al* 2014) provided a greater opportunity of hitting the brain properly. However, the shots in this study tended to be targeted too low (Figure 3). Due to the shifted optimal shot placement, most of them still hit the brain. Perhaps, a new wording to describe the optimal shot placement might facilitate accurate targeting by helping the shooter to visualise the required location easier. This requires replacing the traditional term 'at the intersection of two imaginary lines between (…) eyes and contralateral horns' with the suggestion of a triangle located between the eyes and the crest of the head with the optimal shot placement located at the bisecting line of the upper angle, ie at a point directly below the upper third of this line (M von Wenzlawowicz, personal communication 2013).

Generally, the results of this study emphasised the great importance of accurate shot location. Six out of 13 shots with a deviation $\geq$ 4 cm from the optimal shot placement resulted in an 'ambiguous' or 'poor' stun-quality level, whereas only two of 17 shots with a deviation < 4 cm resulted in an 'ambiguous' stun-quality level (Table 5). This difference indicates that with accurate targeting, the probability of achieving a 'deep' stun was very high. Deviations $\geq$ 4 cm, however, tended to result in a stun quality that was unpredictable and insufficiently reliable. Shooters should be required to provide proof of competence, defined by ability to consistently hit a 'safe' radius $\leq$ 2 cm, regularly. This target size was also recommended for effective captive-bolt stunning (Ilgert 1985; Gregory *et al* 2007; Atkinson *et al* 2013). Feeding the cattle before and during the shooting is not recommended. Their foreheads were not presented at an optimal angle when lowered for consumption of feed and there was less motion in their head carriage in absence of chewing, which facilitated accurate targeting. Employing a riflescope with an illuminated dot can also facilitate precision shooting. Generally, the short distance of $\leq$ 20 m between shooter and cattle has to be taken into ballistic considerations and a control shot before each shot for slaughter purpose ought to be obligatory.

According to Gregory and Shaw (2000), the stun-to-stick interval was irrelevant for animal welfare when a deep stun was provided. While a specific stun-to-stick interval was not specified in the related EC Regulation, it was suggested that undue delay be avoided (EC 2009). However, in this study, the mean stun-to-stick interval was almost twice as long as required by German law. This was due to a time-consuming salvage of the shot animal and might be improved by bleeding directly after hoisting within the shooting paddock instead of outside from it. However, no blood ought to remain on the ground. It was assumed that most of the cattle shot by a gun were not only stunned, but brain dead. Therefore, the danger of regaining consciousness and sensibility to pain was minimised even in cases of a prolonged stun-to-stick interval.

Physical signs indicating a deep stun

In general, each calibre had the potential to cause a 'deep' stun. Six of the eight shots with an 'ambiguous' or 'poor' stun quality came from the 13 shots that deviated ≥ 4 cm from the optimal shot placement (Table 7), which might explain the occurring deficits. The seventh shot was a large-bore shot (8×57 JS) with a deviation from the optimal shot placement of 3 cm and brain haemorrhages classified as 'sufficient'. In this case, the shot passed straight through the skull, which means a considerable loss of energy occurred. No other reasons for stunning deficits were evident in this case. The eighth shot used a small-bore calibre (.22 Magnum semi-jacketed). Its deviation from the optimal shot placement was only 1.5 cm and the related brain haemorrhages were classified as 'sufficient'. However, its depth of penetration was, for unknown reasons, only 6.5 cm (mean depth of penetration: 10.2 [± 2.5] cm), which might be the reason in this case. As it was possible to achieve a 'deep' stun by each of the calibres employed, no preferences regarding a certain calibre could be established, and the deviation from the optimal shot placement turned out to be more important than the use of a certain calibre.

In contrast to the expected higher efficiency of large-bore calibres (.30-06, 8×57), ten of the deeply stunned cattle displaying neither 'muscle spasms of legs after collapse' nor 'muscle spasms of legs during transport' were shot by a small-bore calibre (.22 Magnum semi-jacketed). Previously, clonic convulsions were regarded as common in cattle shot by a captive-bolt gun, following the collapse and a short tonic phase (Grandin 1994; Gregory *et al* 2007; Hilsenbeck 2007). As the .22 Magnum semi-jacketed calibre was the only one remaining in the cranium, the absence of those musculoskeletal reactions might be due to an optimised energy transfer of the projectile into the cranium (Finnie 1997), affecting the brain in a different way than the other calibres or a captive-bolt gun. In 1985, Blackmore had already observed a much smaller degree of post mortem convulsions in cattle shot by a self-constructed multiple projectile, fired from a so-called humane killer with a spring-loaded barrel. He hypothesised the higher intracranial pressure, which successfully depresses reflex agonal movements, was responsible. Reduced clonical convulsions could also be regarded as a work safety advantage during salvage of the shot cattle.

The sign 'tongue protruding', caused by a relaxation of the jaws, may be one of several indicators for a proper stun (Grandin 2002; Gregory 2007). Gregory *et al* (2007), however, reported ambiguous results related to a protruding tongue. This was consistent here, where the tongue was hanging out of three animals assessed as ambiguously stunned (due to distinct or excessive musculoskeletal reactions). Further, even the one vocalising animal had a tongue hanging out. These findings underlined the importance of assessing multiple signs, instead of relying on single factors. Shaw (1989) and Gregory and Shaw (2000) even pointed out that the corneal reflex was not 100% reliable as a single indicator for a deep stun, because a situation might arise where only the specific area of the brainstem that is associated with the corneal reflex is damaged whilst other brainstem functions remain intact.

Vocalisation has been suggested as an indicator of welfare problems at cattle slaughter (Grandin 1998b) and distinct vocalisation was regarded as a definite sign of poor stun quality in this study. Further signs usually considered to be most serious: 'collapse and typical tonic phase', 'breathing', 'corneal reflex', 'spontaneous blinking' and 'eyeball rotation/movement' (Grandin 2002; Algers & Atkinson 2007; Gregory *et al* 2007; Atkinson *et al* 2013), were completely absent in all animals shot by a gun in the present study, even in those seven animals that achieved an 'ambiguous' and the vocalising animal that achieved a 'poor' stun-quality level.

Further research is needed to clarify the relevance of various signs to assess the effectiveness of the shot, the extent that they are tolerable, and how they are related to brain haemorrhages.

Brain tissue damage

The approach for the assessment of brain tissue damage following a gunshot in live cattle was preliminary, because only isolated post mortem cattle heads were employed previously, which were frozen and thawed prior to shooting (Schiffer *et al* 2014). Regarding the present study, the biological importance of brain tissue damage turned out to be negligible (Table 9). The frequent occurrence of severe brain tissue damage in a previous study might be explained by different texture and pressure features in post mortem heads compared to live animals. According to Di Maio (1999), a critical level of kinetic energy loss needs to be exceeded before the elastic limit of the organ or tissue is exceeded and tissue damage becomes radically more severe ('bursting'). In those previous (isolated) heads, intracranial pressure conditions as well as autolytic processes that might have already started and influenced the texture (or elastic limit) of the brain tissue were likely to differ from live animals.

Brain haemorrhage

In the present study, it was possible to cause 'sufficient' brain haemorrhages with all calibres used (Table 10). In 21 out of 25 cases, 'sufficient' haemorrhages were associated with a 'deep' stun. In those five cases with 'insufficient' brain haemorrhages, three were associated with an 'ambiguous' stun and one (which failed to hit the brain completely) with a 'poor' stun (Table 11). This underlines the close relationship between brain haemorrhages, especially at the region around the brainstem, and stun quality. For four shots causing 'insufficient' haemorrhages, the high deviation from the optimal shot placement was hypothesised to be the reason. The deviation of the fifth shot was even higher and the projectile did not hit the brain at all. Brain haemorrhages occurred only close to the trajectory, ie dorsally and basally at the left rostral cerebrum. The related stun quality, however, appeared to be 'deep'. This might be explained by the high kinetic energy of the large bore employed in this shot (8×57 JS, approximately 4,000 J). In cases of a failed shot by such a large-bore calibre, it might happen that the animal collapses and appears to be effectively stunned, due to the power of the shot, although the impact on the brain was comparably less and the animal was unlikely to be brain dead (which was expected when severe brain haemorrhages occur). Consequently, the danger of regaining consciousness might be higher than in a properly hit animal.

Four animals were assessed as ambiguously stunned according to the relatively strict stun-quality protocol (related to musculoskeletal signs) although their brain haemorrhages would have been ‘sufficient’ based on the subsequent dissections (Table 11). This might be an indicator of musculoskeletal signs being less crucial for evaluating stun quality. However, from an animal welfare perspective, placing a back-up shot as soon as any doubt arises appears to be generally recommended. Moreover, in practice, the decision on a back-up shot needs to be taken *in situ* and immediately, so it should be based on the assessment of the physical signs displayed after the shot.

Animal welfare implications

Shooting an animal that is allowed to remain in its common flock avoids stress, increases calmness of the setting and, thus, facilitates accurate targeting, which is the most critical aspect when the gunshot method is employed. In order to ensure a maximum degree of animal welfare until the onset of death and provide a high standard of work safety matters, regular proof of the shooter’s competence is strongly recommended.

Conclusion

The stun-quality protocol employed in this study helped assess the efficiency of a gunshot at cattle. Following an accurately placed shot, all calibres tested revealed the potential to inflict a deep stun in smaller cattle breeds, such as German Angus or Galloway. The related brain haemorrhages were supposed to be sufficient as they included the crucial area around the brainstem. The .22 Magnum with semi-jacketed projectiles represented a solution for not-passing shots, ie the projectiles remained within the cranial cavity which is highly favourable from both an effectiveness and a safety perspective. Within the context of this study, tissue damage was evaluated as being of less importance than brain haemorrhage for the assessment of stun quality following gunshot at cattle. Further research is required to verify these results.

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