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Animal Welfare Aspects of Mechanical Stunning and Killing of Neonate Farm Animals and Mechanical Stunning of Adult Cattle

Presentation for

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Animal Welfare Aspects of Mechanical Stunning and Killing of Neonate Farm Animals and Mechanical Stunning of Adult Cattle

Andrew Grist

A dissertation submitted to the University of Bristol in accordance with the requirements for award of the degree of Doctor of Philosophy in the Faculty of Medical Sciences

54,172 Words

Synopsis

This work covers research carried out over three years (2016-2019) focusing on the use of captive bolt devices to euthanase and/or stun animals reared for meat production.

Chapter One reviews the development of mechanical stunning of meat animals, from the pre 1800's to date in the United Kingdom, looking at the development of the current captive bolt devices used extensively within the meat industry. It examines the current understanding of the use of captive bolt devices and their effect on the animal and introduces the current euthanasia methods used on farm for neonate animals.

Chapter Two focuses on the euthanasia of neonate animals during the production phase using mechanical non-penetrating captive bolts. This research examined a commercially available non-penetrating captive bolt designed for poultry euthanasia, to assess the power (Kinetic energy) required to successfully stun/kill neonate piglets. with one application and also to determine shooting positions to ensure this effect. These two papers cover work funded by Alberta Agriculture and Forestry, to examine the effectiveness of the Bock Industries Zephyr EXL for the euthanasia of piglets up to 10Kg liveweight.

Chapter Three These three papers present the results of a DEFRA funded project focusing on the use of the Accles and Shelvoke Small Animal Tool to stun/kill neonate piglets, lambs and goats, to assess the efficacy of the device in ensuring a single application stun/kill method, and also to determine a shooting position for each species.

Chapter Four examines the use of commercially available penetrating captive bolt devices for the humane stunning of cattle prior to slaughter, focusing on issues that may lead to an ineffective stun. Paper six examines the use of macroscopic examination of heads to assess stun issues to provide guidance and training for abattoir staff. Paper seven represents the first in-depth examination of cartridges and their variation in generated power and hence their ability to produce sufficient kinetic energy to stun. By examining both heads and cartridges we are able to provide government agencies and abattoir personnel reinforcement of current practices, guidance to reduce the need for secondary stun attempts and provide avenues that should be considered to reduce the number of ineffective stuns.

Chapter Five discusses the research undertaken, in particular its implications, and suggests further research options that can be carried out in the same vein to improve welfare at slaughter with currently available devices.

Dedication and Acknowledgements

The first person to whom this is dedicated is to my wife, Grace, without whose patience, support, coffee provision, proof reading and encouragement this thesis would never have materialized, but also to my father, Ken Grist who inspired me up to the day of his passing and has carried on inspiring me since.

Acknowledgements and thanks must include Steve Wotton, MBE for his friendship, his support. patience and enthusiasm, and my two supervisors Dr Ed van Klink and Professor Toby Knowles without whom this would definitely not have been written. Thank you all for your patience and continued support.

Lastly, thanks to my two dogs; the beauty of having Basset hounds is that no matter how tired you are – they always look more exhausted!

Author’s declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: Andrew Grist DATE: 08/01/2020

List of papers for consideration:

Humane Euthanasia of Neonates I: Validation of the Effectiveness of the Zephyr EXL Non-Penetrating Captive Bolt Euthanasia System on Neonate Piglets up to 10.9 kg Liveweight
Grist, A., Murrell, J.C. McKinstry, J.L., Knowles, T.G and Wotton, S.B.
Animal Welfare 2017, 26: 111-120 ISSN 0962-7286 doi: 10.7120/09627286.26.1.111

Humane euthanasia of neonates II: Field study of the effectiveness of the Zephyr EXL non-penetrating captive-bolt system for euthanasia of newborn piglets
Grist, A., Knowles, T.G. and Wotton, S.B
Animal Welfare 2018, 27: 319-326 ISSN 0962-7286 doi: 10.7120/09627286.27.4.319

The use of a non-penetrating captive bolt for the humane Euthanasia for neonate piglets.
Grist, A., Lines, J.A., Knowles, T.G., Mason, C.W. and Wotton, S.B.
Animals Special Issue on Euthanasia, Animals 2018, 8, 48; doi:10.3390/ani8040048

The use of a non-penetrating captive bolt for the Euthanasia of neonate goats
Grist, A., Knowles T.G., Mason, C.W. and Wotton, S.B.
Animals Special Issue on Euthanasia, Animals 2018, 8, 58; doi:10.3390/ani8040058

The use of Mechanical Non-penetrating Captive Bolt Device for the Humane Euthanasia of Neonate Lamb
Grist, A., Lines, J.A., Knowles, T.G., Mason, C.W. and Wotton, S.B.
Animals Special Issue on Euthanasia, Animals 2018, 8, 49; doi:10.3390/ani8040049

Macroscopic examination of multiple shot cattle heads – an Animal Welfare due diligence tool for abattoirs using penetrating captive bolt devices
Grist, A., Knowles, T.G. and Wotton, S.B.
*Animals **2019**, 9(6), 328; https://doi.org/10.3390/ani9060328*

An examination of the performance of blank cartridges used in captive bolt devices for the pre-slaughter stunning and euthanasia of animals
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Declaration of candidate input:

We confirm that the candidate input for the papers listed in the previous section and submitted for this dissertation are accurately listed at the start of each chapter on pages 46, 96 and 194

Andrew Grist – First Author Date 08/01/2020

Stephen Wotton – Author Date 08/01/2020

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Chapter One
Introduction to Mechanical Stunning and killing of Meat Animals

1.1 A review of the development of mechanical stunning in the United Kingdom

Today we use terms such as ‘animal welfare’ and ‘humane’ to describe the legislative and moral requirements to render an animal unconscious before causing the death of the animal by bleeding, but this is still a relatively modern philosophy. Cattle have been rendered immobile for slaughter since before the middle ages; but this was a practical choice rather than a welfare driven decision, the immobility allowing a large, possibly dangerous animal to be processed safely by the butcher *(*Editorial*, Comparative Pathology and Therapeutics, 1893)*. The fate of smaller animals, even up to the 1930s in England was to be bled whilst conscious. Some of the methods used for cattle appear barbaric by today’s standards but must be taken in context of the scientific understanding and technological abilities of the period. For example, Dr Carson’s patent slaughtering method for cattle (Mechanics magazine 1839; The Lancet,1860) represented what would now be considered a truly horrific method of slaughter, by the mechanical induction of pneumothorax and the subsequent death of the conscious animal by asphyxiation rather than exsanguination. However, this method was designed to retain blood within the animal as, at the time, this was considered beneficial. Nevertheless, this method must be considered as a product of the time, 20 years before the publication of Darwin’s ‘On the Origin of Species’ and one year before the British Government introduced the Vaccination Act (1840), following Edward Jenner’s experiments with smallpox. We can therefore consider the historical background to the development of stunning devices for cattle beginning around the year 1830 but taking a further one hundred years to reach fruition. This is a period where there are no municipal slaughterhouses, slaughtering takes place in butchers’ establishments and on-farm. In 1892, for example, there were approximately 600 butchering slaughterhouses in London alone and 50 in Coventry (Macnaughten,1926).

This review examines the methods used to mechanically 'stun' animals prior to slaughtering, focusing chiefly on those used for cattle as it was customary for sheep, pigs and calves to be bled unstunned, until the early to mid 20th Century in the United Kingdom. In deciding the best method to format this review, an approximate date order was decided upon. Not all the devices patented and described in this review were produced commercially, their inclusion was considered necessary to provide a more complete picture of the development, and some methods are not included in this review such as free bullet devices, controlled atmosphere killing (Ward Richardson,1885) or shaped dynamite charges (The Lancet, 1877).

1.1.1 Legislative Background in the United Kingdom

Slaughter of Animals Act 1933 Section I,1. No animal to which this section applies shall be slaughtered in a slaughterhouse or Knackers yard except in accordance with the following provisions, that is to say, every such animal shall be instantaneously slaughtered, or shall by stunning be instantaneously rendered insensible to pain until death supervenes, and such slaughtering or stunning shall be effected by means of a mechanically operated instrument in proper repair'

The above excerpt from the Slaughter of Animals Act 1933 represented a milestone in animal welfare, the first time the requirement to mechanically stun all animals prior to slaughter was introduced into national legislation in England and Wales (Scotland outlawed poleaxe use in 1929). This compares to Switzerland where the requirement to stun all animals before bleeding was introduced on August 20 1893 (Macnaughten, 1926) thereby prohibiting religious slaughter (i.e. slaughter without prior stunning), and by Germany in 1890. Previous to this, national legislation attempts had been made to make the preslaughter stunning of cattle compulsory by the introduction of model by-laws through the Local Government Board (later to become the Ministry of Health) in 1900. These model by-laws were made under the Towns Improvement Clauses Act of 1847 and Section 169 of the Public Health Act 1875 that imposed on local authorities a statutory duty for producing by laws to prevent cruelty in slaughterhouses and knackers yards.

1.1.2 Admiralty Committee 1904

In 1904 a committee was appointed by the Admiralty (who supplied their own ships with meat through victualing yards) to investigate the humane slaughtering of animals, (Minutes of evidence,1904). The committee consisted of seven members, the chairman, Mr Arthur Lee, Colonel F.T. Clayton, Mr Alexander Cope, Mr Charles Game, Mr Gordon Miller, Mr Shirley Murphy, Sir Henry York K.C.B. and the secretary Mr Hayes. These men represented the Admiralty, the War Office, Department of Agriculture, London County Council and the City of London Markets Committee. The first evidentiary hearing took place on Monday 8th February 1904, and over succeeding meetings evidence was taken from 20 witnesses. The main thrust of the questions was the stunning methods for cattle and their efficacy, the stun or non-stun of sheep and pigs, and the training and possible licencing of slaughtermen. The witnesses called represented a wide cross-section of interested parties including:

Mr William Wilkinson Smart - Veterinary Inspector at Deptford abattoir

Mr William Edwin Powell – Master butcher at the victualing yard, Gosport

Mr Henry James Holder Tuck – Inspector to the Public Health Department, London County Council

Mr Seth Lewis – Inspector to the London County Council

Mr H.C.Monro – Assistant secretary of the Local Government Board

Mr James King – Veterinary Inspector to the Corporation of the City of London

Mr Henry Grant – Butcher

Mr William Reid – Carcass Butcher

Mr John Colam – Secretary of the RSPCA

Professor William Pritchard FRCVS – Royal Veterinary College

Mr William Hunting – Veterinary Inspector to the London County Council

Captain W. Melville Lee – Army

Mr William Haydon – Master Butcher, London Master Butchers' Association

Mr W.N. Wycherley – Chief Meat Inspector to the City of Liverpool

Mr Peter Durie – Superintendent of the Edinburgh Slaughterhouse

Mr Clare Sewell Read – Ex Member of Parliament

Captain E.F. Inglefield – R.N.

Sir Samuel Montagu – President of the Shechita Board

Dr Carl Budding – Local Government's Board at Coblenz

The report of the Admiralty Committee provided a set of recommendations that led to the construction of the first 'model' slaughterhouse at the naval dockyard at Chatham. The recommendations produced by the Committee included that all animals should be stunned or otherwise made unconscious before blood is drawn, private slaughterhouses should be replaced with public ones, meat inspection should be enforced in all public abattoirs and licensing should be compulsory for all slaughtermen. These recommendations were not universally adopted, a circular printed in the Lancet in 1908 (Humane slaughtering of animals, The Lancet, March 28, 1908) attested to the delay in local authority uptake in all aspects of the report's findings, including the recommendation that slaughtermen be trained and licenced. The Ministry of Health modified their model by laws to include Clause 9b following the Admiralty report, stating that *"A person shall not in a slaughterhouse proceed to slaughter any animal until the same shall have been effectively stunned with a mechanically operated instrument suitable and sufficient for the purpose."* Various councils enforced these by-laws after a delay, Southampton introduced Clause 9b in 1916 after receiving a 16,000 signature petition, London Borough Council introduced 9b in 1923 (Report of the Medical Officer of Health for London County Council, 1923 pp118-119) which was approved by the Minister of Health (Neville Chamberlain) that same year after modification of the proviso relating to the slaughter of animals for Jews. Even with this time lag, for local authorities to produce these by-laws, the National Federation of Meat Traders Association failed with two petitions in 1915 and 1921 to have Clause 9b removed. The Journal of The Society of Engineers 1910 stated that in that year in England and Wales the population consumed 119 lbs (54 Kg) of meat per head, only 10.5% (12½ lbs (5.7 Kg)) of which was killed in the 104 public abattoirs, the remainder came from private slaughter establishments.

1.1.3 Stab Nape

The use of a stab-nape, nape-stab or puntilla knife (Figure 1) was commonplace in the early 19th Century as a slaughter method for cattle. The basis of the method was the need to exert control on the animal during the bleeding process. A knife (stab nape) was inserted between the occipital-atlanto joint at the rear of the head to sever the spinal cord. The effect of this is, to effectively paralyse the animal to facilitate bleeding and dressing, in a safe manner, for slaughtermen. The animal would have been conscious throughout the bleeding operation and would have died from haemorrhagic shock or asphyxia. This method was still used in the Lisbon abattoir in Portugal in 1907 (The Lancet, March 9, 1907)

Figure 1*: Two nape stab knives with characteristic diamond shape tips*

1.1.4 Poleaxe

The poleaxe, also known as a felling hammer and poll axe, was the preferred method of stunning cattle prior to the late 1890's, and it continued to be used until prohibited by legislation in 1929 in Scotland and 1933 in England and Wales. Various designs were available with an axe end, hammer end or hook end but all had a common 'thimble' or punch end (Figure 2). The tool was designed to be multifunctional, an axe end was used to remove horns and split the carcase, a flat or hammer end was used in skinning the carcase and the hook-ended type was used to relocate animals that had fallen in an inappropriate position for further dressing and also facilitate removal of the punch from an animals head should it become embedded (Figures 3-6). This secondary role was continued, following the ban on their use; by local authorities removing the punch end.

***Figure 2**: The punch of a pole axe (Author's Collection)*

The basic concept of the pole axe was to drive the punch or thimble end with force into the forehead of the animal to concuss it, this was then followed by the insertion of a pithing cane to kill, and prevent movement of the animal during dressing, by destroying the spinal cord.

Issues encountered with the use of the pole axe for stunning cattle included restraint, accuracy, reproducibility, staff training and technique. The restraint required for an accurate blow involved tethering the animal to a ring on the floor or wall, depending on the preferences of the slaughterman, and some animals were manually restrained by operatives. In terms of accuracy it was known before the 1900's that cattle could require more than one blow to stun. The Corporation of London report cites figures of average 2.5 blows for bulls, 1.23 for oxen and 1.27 for cows. Mr Ernest D. Evans, Chairman of the United Tanners' Federation of Great Britain and Ireland sampled the first 100 hides received and counted the number of holes in the head area, not only giving an average of 1.74 blows per animal but also finding one animal had 10 perforations in the head skin.(Table 1)

Blows	Hides	Blows, Total
1	55	55
2	30	60
3	10	30
4	1	4
5	3	15
10	1	10
	100	174

*Table 1. Poleaxe Blows per animal. Mr Ernest D. Evans, Chairman of the United Tanners' Federation. Report of Speech made at a Public Meeting of the Animal Defence Society held at Bristol March 22nd 1923 (*The Animal Defence and Anti-Vivisection Society, reports, 1923 and 1924*)*

***Figure 3**: Hook end poleaxe (Author's collection)*

There were not only concerns over the reproducibility of the poleaxe blow, but also in the teaching in its' use. The Ministry of Agriculture Circular of March 5th 1921 stated that "*We may remember the men who wield the poleaxe skilfully are in the minority, and that all beginners must, or rather do, learn by actual practice on living animals."* The Annual report of the Medical Officer of Health, Brighton 1925, described the formation of a committee to oversee the licencing of slaughter personnel, in July 1921 *"skilled men were asked to come forward and demonstrate their skill by stunning a bullock with the first blow. In all twenty men were tested, and of these four failed to pass the test, a failure rate of 20 per cent…It was later found that some of the men who passed the test were later having miss hits."* A further quote, from Mr John Robertson, Wilsons Ltd Edinburgh 1921 *"Even an expert golfer will miss-hit the ball occasionally"*.

Figure 4: *Poleaxe in use in France. Note use of blindfold (Author's collection)*

In addition to accuracy, maintenance of the poleaxe was called into question, in the Bexhill Chronicle of the 19th August 1922 (Macnaughten,1926) a Mr R.F.J. Foslett was reported as saying that "*I saw a beast struck several times without falling and* *inquired of the slaughterman why. He showed me the poleaxe, and told me it should have been scrapped long ago. It certainly seemed blunt, worn and clogged and obsolete when compared with those used at Islington."* In the Animal Defence and Anti-Vivisection Society, reports, 1923 and 1924, the superintendent of the Stirling abattoir stated that *"As a rule butchers do not keep their poleaxes in a very good condition…they are oftener more blunt than sharp."*

Mr John Dodds, Superintendent of Carlisle Abattoir wrote in the Animal Defence Society's Pamphlet of 1925; *"Only recently, I witnessed a small Ayrshire cow with the axe driven in near the eye and pulled out again, and as the poor creature did not return to the position the slaughterman wanted, he took the axe head in his hands and struck it with the full length of the shaft"* (Macnaughten,1926)

The techniques used for poleaxe stunning also varied, although all the evidence suggests that the head was restrained, some witnesses in the admiralty report describe a two strike method with some animals, with an initial shot to the back of the head to prostrate the animal followed by a second strike to the forehead to stun. Other slaughtermen of the period described the practice of removing the thick skin over the forehead on mature bulls prior to stunning to allow unimpeded access to the frontal bone (Macnaughten, 1926 p22). Both of these techniques point to the assertion of Mr Brennan de Vine, City Veterinary Surgeon, Birmingham, that the use of the poleaxe was to immobilise the animal rather than stunning for reasons of humane slaughter; *"Stunning was introduced mainly for the safety of the staff and those handling the animals"* (Macnaughten, 1926, p22)

Figure 5*: Hammer end pole axe (Author's collection)*



Hook head | Chopper Head | Hammer head

Figure 6*:* Poleaxe head types *(Author's collection)*

In their testimony to the 1904 committee appointed by the Admiralty to consider the humane slaughtering of animals Mr William Wilkinson Smart, (Veterinary Inspector at Deptford abattoir with 27-year's experience in an abattoir slaughtering 600-800 cattle a day, including imported cattle from America), Mr William Edwin Powell, (Master butcher at the victualing yard Gosport, 8-years experience at Gosport and a butcher before, 20-40 cattle per day) and Mr Henry James Holder Tuck (Inspector to the Public Health Department, London County Council, veterinary surgeon and inspector for 12 years) described the use of the pole axe.

Mr William Wilkinson Smart:

14 "*First of all they are placed in a fasting pen, a pen outside the slaughterhouse, and there a chain is put round the bullock's neck, and the end of the chain – or the rope, whichever is used – a chain usually – is brought through the open slaughter-house door and put through a fixed ring in the wall, and the animal's head is drawn down comparatively near the ground. Then it is struck on the top of the head with the poll-axe…..(16) that brings them to the ground and they fall on their side; then they are struck there* (forehead)….*a pithing cane is put through here and goes into the spinal cord and smashes up the brain and particularly the medulla oblongata and the first portion of the spinal cord."*

Mr William Edwin Powell*:*

255 "They have a rope round the neck when they are tied up in the pound. The foreman of the slaughtermen takes the rope and catches one as it is driven in; and directly the bullock is in position he holds it by the horns, and a man hits it with a poll-axe….(257) at the back of the head…."

269 "I understand you take the animal into the slaughterhouse and one man holds *his horns; does he stand in front of him? – Yes"*

270 "He holds him with one horn in each hand? – Yes"

271 "And then a second man strikes him on the back of the neck? – Yes"

272 "Then the animal drops? – Yes"

273 "Then do you poll-axe him in the forehead afterwards? – Yes"

274 "And then pith him? – Yes"

276 "But you always have the two blows, the stunning first and the other afterwards? – Yes"

Mr Henry James Holder Tuck:

385 "What is the method employed for killing a bullock? – It is generally killed by pole-axe and a cane is used to pith it, which passes down the spinal column."

392 "And you have not seen animals held by the horns and then struck on the top of the head first? – No. There is a method I believe employed – I have seen it in the public slaughterhouses – for instance, Islington Cattle Market, where they strike the animal on the poll, but it is then necessary to strike the animal in the forehead before you can get an opening for the cane."

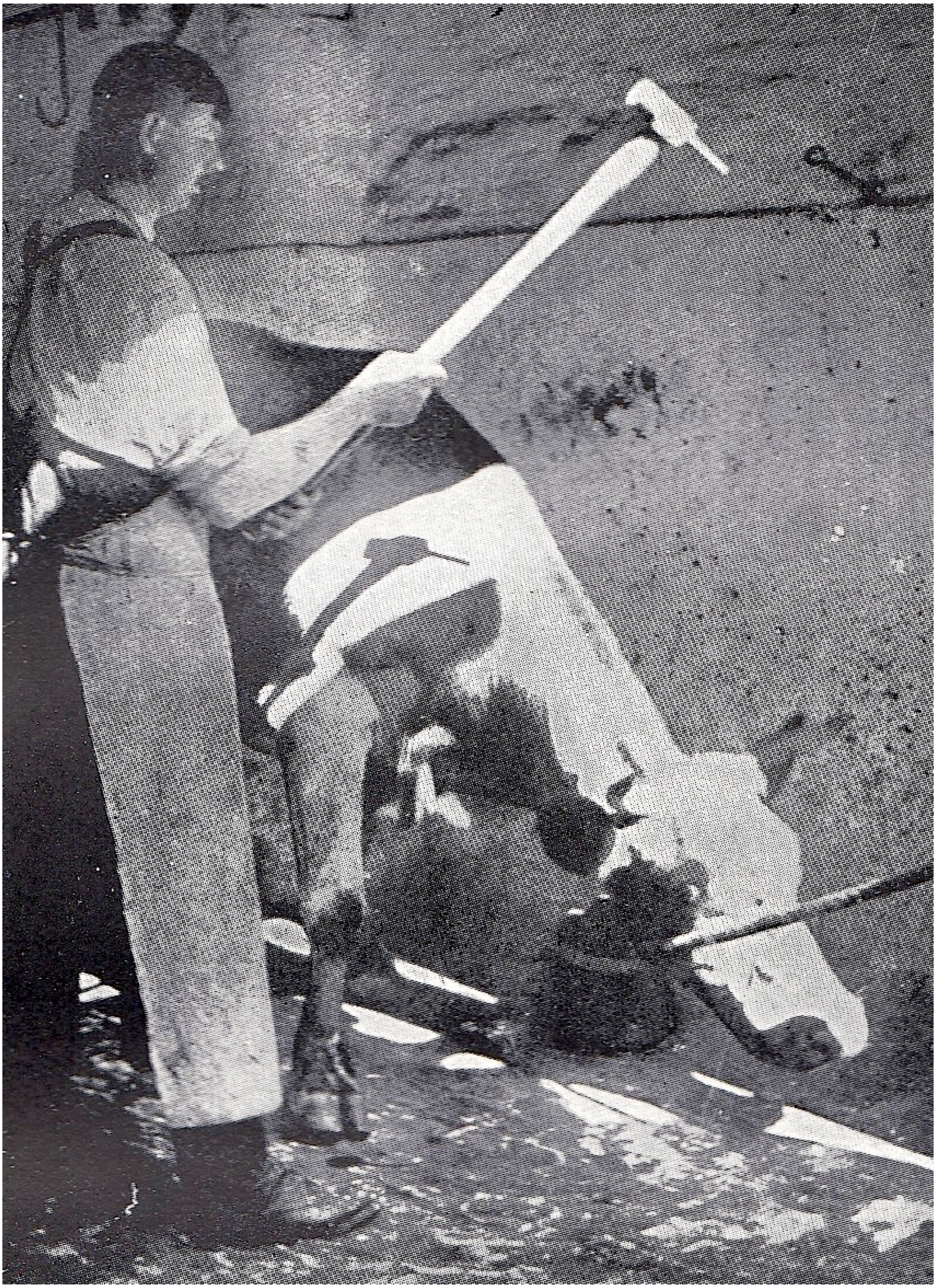

Figure 7: *Poleaxe stunning*
(Pistol v Poleaxe. A handbook on humane slaughter. (Macnaughten, L., 1932)

***Figure 8**: Poleaxe use (1905), note blindfold use and head restraint through floor ring (Author's Collection)*

1.1.5 Bruneau Mask

To reduce the inaccuracy of the pole axe blow, various masks were developed to position a punch in the correct position on the forehead of cattle. The most prominent of these were the Bruneau mask (1872) and the Baxter mask (1874) (The Basle Model Municipal Abattoir, The Lancet, May 1907*)*. The Bruneau mask, invented by François Bruneau of the large La Villette Municipal Abattoir in France (Patent of Invention No. 96 760 of October 4, 1872); consisted of a leather blindfold shroud containing an iron centre with a 15mm diameter bolt. (Figure 9).The mask was placed on the animals' head, strapped into position and then struck with a large mallet. (Figures 10 – 14), The bolt was driven four to five inches (10-13 cm) between the hemispheres, carrying with it a disc of bone (or bone shards), which it punches out shattering the surface of the brain and damaging blood vessels. The French

Society for the Protection of Animals awarded this design first prize in 1874. Although used extensively in the continent, especially Germany and France, and occasionally in the UK, the masks were unpopular in the latter country as the cattle processed in England tended to be more aggressive and the process of fitting the mask delayed operations. In his essay on humane slaughtering, Hugo Heiss, the abattoir superintendent in Bavaria, noted that *"care must be taken to prevent it [the mask] from slipping to one side, since this would involve injury to only one side of the brain."* (C.Cash 1907). In his evidence to the 1904 committee, appointed by the Admiralty to consider the humane slaughtering of animals, Staff-Sergeant Major Fielder – Master butcher at Aldershot, with 18 years' experience, slaughtering 25 cattle a day, stated:

131" We use the mask; we used the poll-axe up to about two months ago, but we use the slaughtering mask now…..(133) Most butchers prefer the poll-axe, but that is only on account of the trouble putting the mask on. I think in regard to humanity the mask is best…."

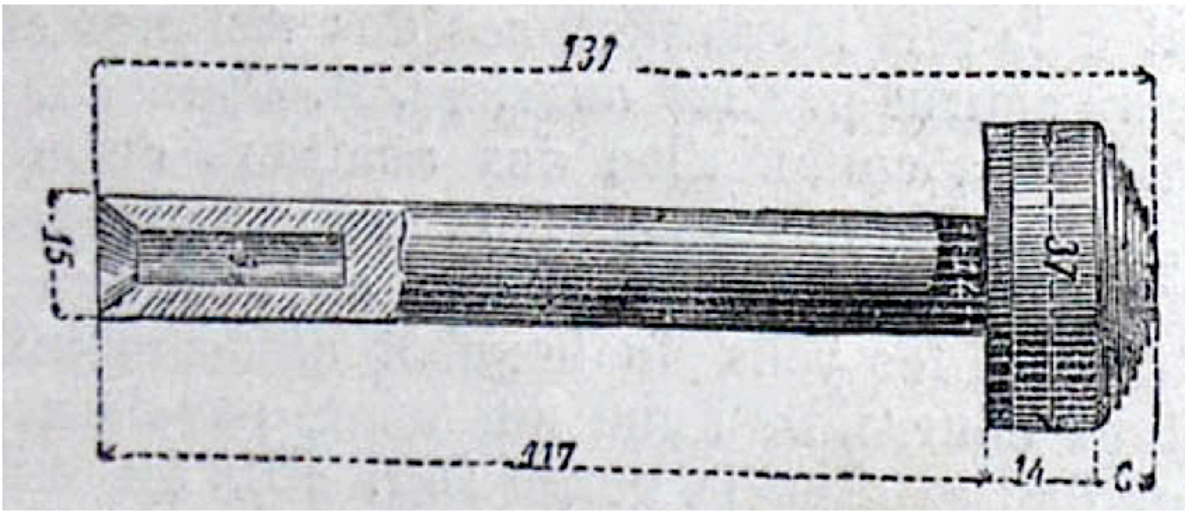

***Figure 9**: Bolt design for Bruneau mask (dictionnaire d'Agriculture de Barral et Sagnier – 1892)*

***Figure 10**: Bruneau mask (Author's collection)*

***Figure 11**: Bruneau mask (Author's collection)*

***Figure 12**: Bruneau mask in use (Author's Collection)*

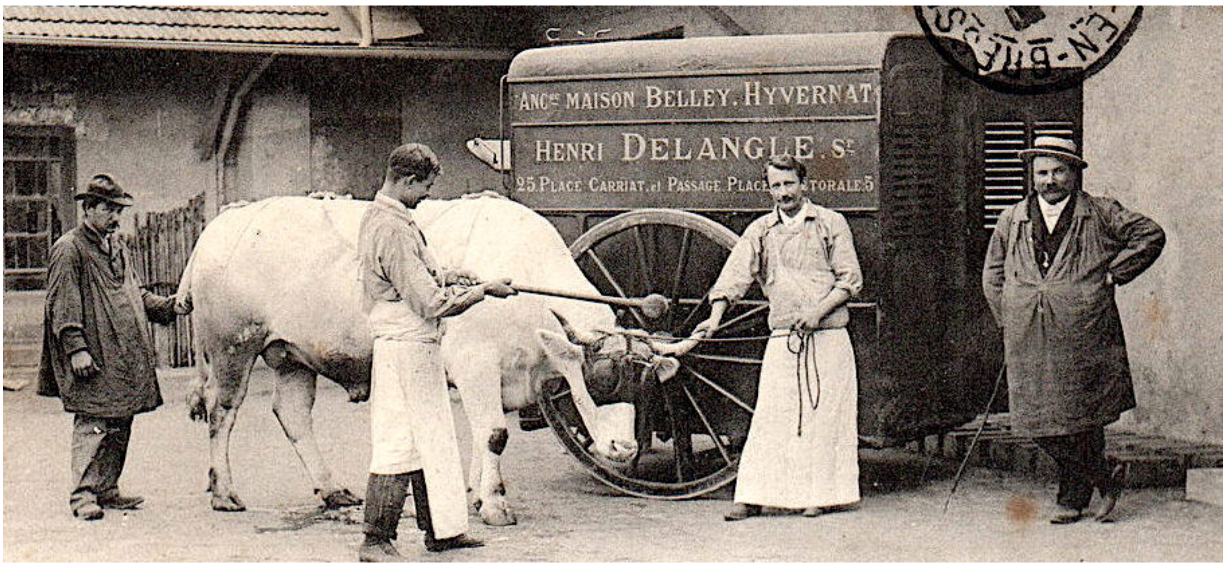

***Figure 13**: Bruneau mask in use. France. (Author's collection)*

***Figure 14**: Bruneau mask, Manual restraint*

1.1.6 Kleidschmidt apparatus

This stunning tool was used in German, Swiss, Dutch and Scandanavian abattoirs for the stunning of pigs prior to bleeding. Its' use required two slaughtermen, one to hold the apparatus on the pigs' forehead and the other to strike the bolt with a large headed mallet. In these abattoirs a pig trap was employed, restraining the animal whilst allowing access to the forehead (Figure 15). The apparatus consisted of a sliding bolt punch held captive within a collar attached to a handle. Most designs incorporated a punch with a cutting surface akin to the thimble end of a poleaxe (Figure 16 & 17). S.M. Dodington, in his report on Public Slaughterhouses in the Journal of the Society of Engineers (1910) reported that in German abattoirs a fine of 3 shillings was imposed for not stunning a pig on the first attempt.

Figure 15*: Kleidschmidt apparatus in operation, note individual restraint of pig*

Figure 16*: A variant of the Kleidschmidt apparatus – punch detail (Author's collection)*

Figure 17 *A variant of the Kleidschmidt apparatus (Author's collection)*

1.1.7 Finke Captive Bolt 1902

One of the precursors for the modern captive bolt pistol was patented by Emil Finke of Bremen, Germany in 1902 (PAT No GB11088) (Figure 18). The design provided for one or more hollow bolts to be driven into the brain allowing the exhaust gases to potentially destroy brain matter.

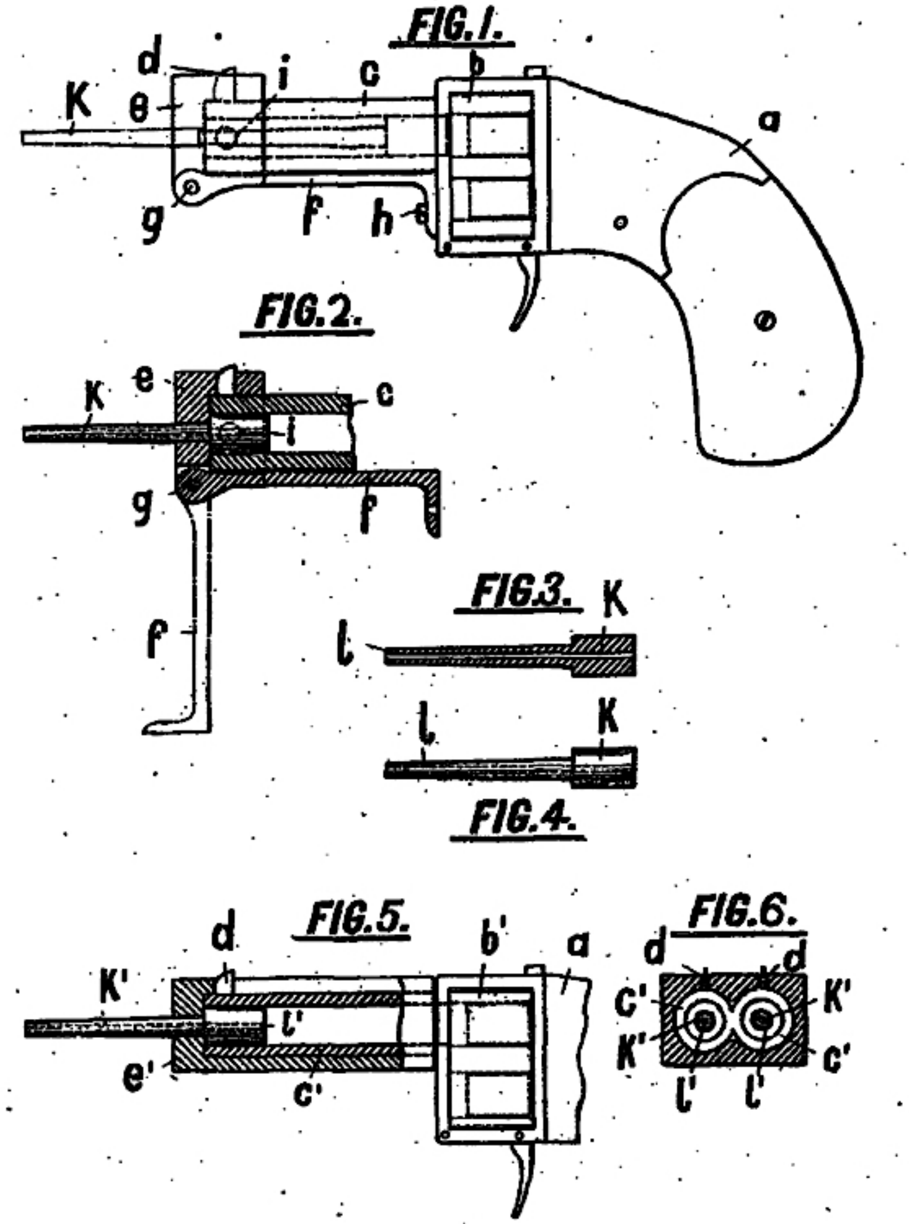

Figure 18: *Original patent drawing for Finke's stunner*

1.1.8 BEHR'S "FLASH" CATTLE KILLER 1904

The Behr 'Flash' Cattle Killer represented the first captive bolt, or mechanical pole axe that entered general use and refined the ideas of Finke (1902). It was designed in response to an open competition by Burkard Behr of Behr's Industrial Company, Hamburg and patented in 1905 (Pat No US801839) (Figure 19).

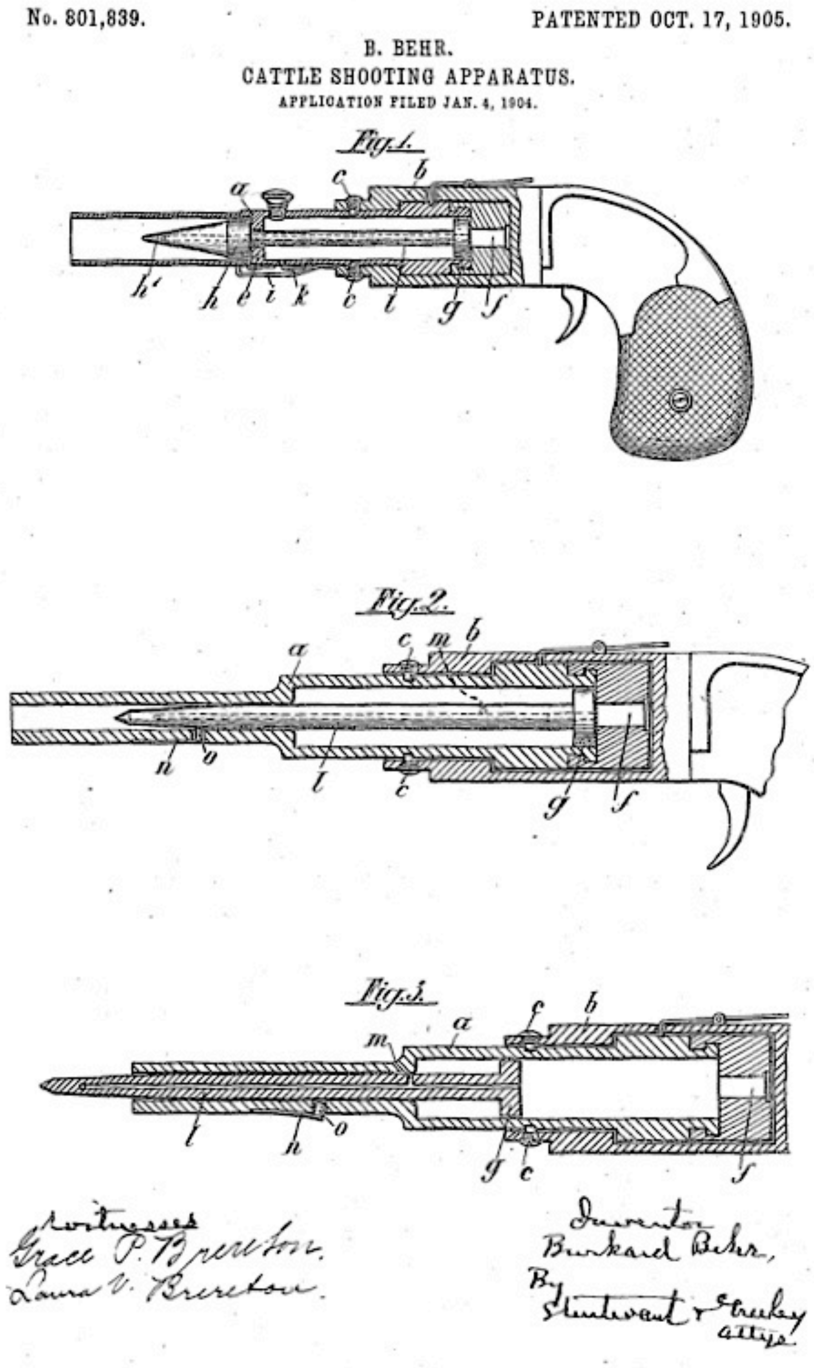

***Figure 19**: 1905 Original patent for the cattle killer*

***Figure 20**: Behr's "Flash" Cattle Killer (Author's collection)*

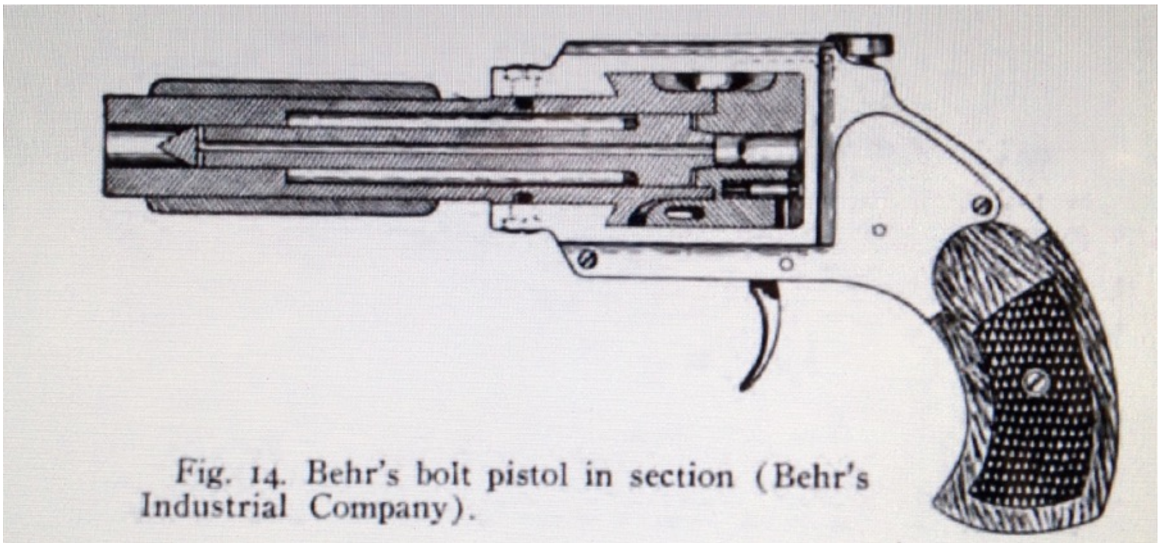

***Figure 21**: Diagram of Behr's "Flash" Cattle Killer (Richard Edelmann)*

The pistol was a breech loading ejector pistol (figures 21 – 22) using either an 8mm or 9mm calibre blank cartridge as the propellant source for a captive bolt (Figure 23). The original design had a pointed (conical) bolt end, with a central hollow gas vent leading to two vents drilled at the sides of the base of the point. The effect of this innovation was the discharge of the propellant gas into the brain tissue following the high velocity impact to the cranial cavity, destroying the brain structure and preventing recovery from the stun. The bolt retracted into the breech due to compression of air within the barrel. The device was later further modified by alteration of the end of the bolt to resemble the punch of a pole axe whilst retaining the discharge vent system.

***Figure 22**: Later model of Behr's "Flash" Cattle Killer with head plate (Author's Collection)*

The Behr captive bolt was produced in two variations; No1 using a 9mm blank cartridge containing 0.25-0.30 g (3.86-4.63 grain) propellant for cattle and large animals and type No 2 using an 8mm cartridge containing 0.15-0.18 g (2.31-2.78 grain) propellant for smaller animals. (*L'Illustration February 1905*)

***Figure 23**: 8mm blank cartridge for Behr cattle killer (municion.org)*

1.1.9 Christopher Cash and Accles and Shelvoke

One of the most influential names in the development of mechanical stunning apparatus was Christopher Cash (1864-1925), of Coventry. Christopher Cash travelled Europe looking at methods of animal despatch within abattoirs, having independent means as a member of the family that designed and produced woven name tape and labels for the clothing industry. He campaigned for improvements in slaughter and public health, writing a book 'Our Slaughterhouse System; A plea for Reform' that included a translation of the abattoir system used in Germany by Hugo Hiess. As part of his campaign he also produced pamphlets including 'The Humane Slaughtering of Animals for Food' published by the RSPCA. Following experimentation with captive bolt devices in Europe, including the Behr cattle killer, Christopher Cash started developing ideas for a 'mechanical pole axe'. He initially teamed-up with a gunsmith, Albert Thompson from Coventry, to develop the idea of a spring powered mechanical pole axe which was patented in 1912 (Figure 24).

The development of what we know today as a captive bolt pistol began in earnest when Christopher partnered with James George Accles, a consulting engineer, to produce workable models. In 1910, Christopher had 4000 animals (from 30 butchers) killed using ‘humane’ methods, offering to compensate the owners should any deleterious effects be found within the carcass. At that time the reduction of meat quality was a major excuse used by the powerful meat industry to prevent mechanical stunning from being encouraged however, no compensation was ever claimed. *(Galsworthy 1913)*

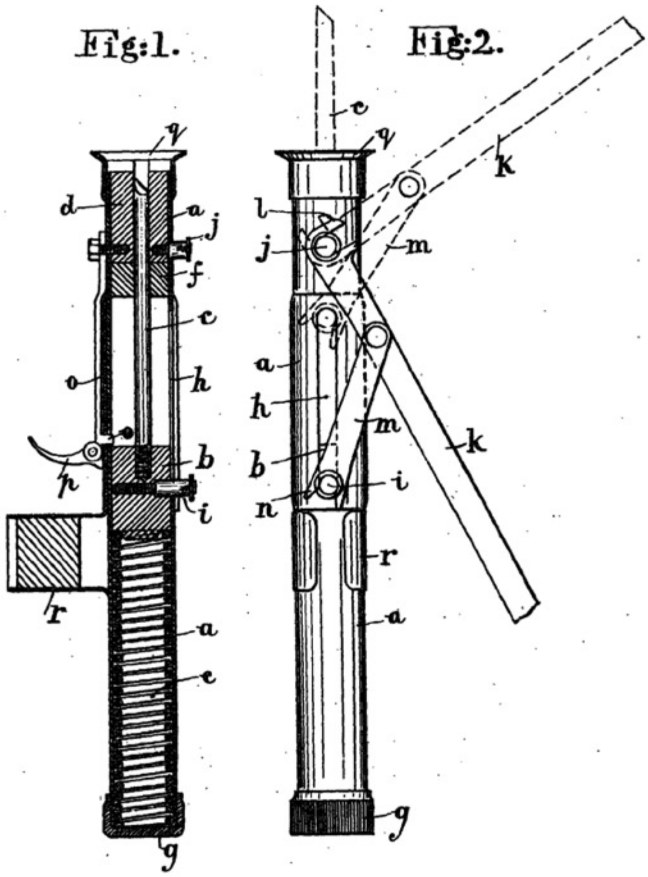

***Figure 24**: Original 1912 patent drawing by Christopher Cash for a ‘mechanical pole axe’*

The first production version of the CASH mechanical pole axe was accepted for use and endorsed by the RSPCA in 1913. The first world war halted the production for a period of time, but the RSPCA gained permission from the government to carry on the supply of cartridges to those who already possessed a Cash gun.

The original patent (Figure 25) describes an adjustable gauge fitted to the barrel to adjust the depth of bolt penetration depending on species. In addition, the return of the bolt into the breech was achieved by the action of air compression in the front of the barrel expanding after the shot. The gun (Figure 26) opened by pivoting the barrel and an ejector mechanism on a cam raised the cartridge in a manner similar to that of shotguns.

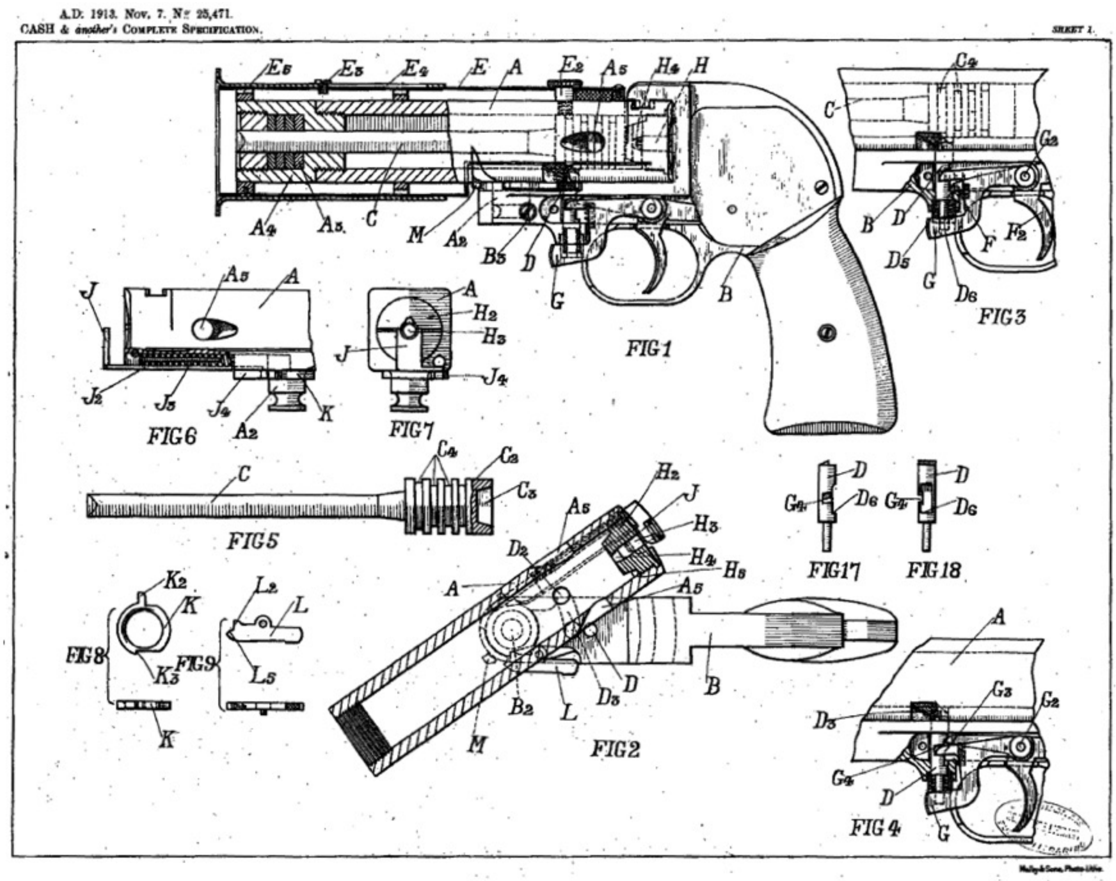

***Figure 25**: Original 1913 patent drawing (25471) for the CASH RSPCA captive bolt pistol*

Figure 26: *Accles and Shelvoke CASH RSPCA Captive Bolt Pistol (A&S Museum)*

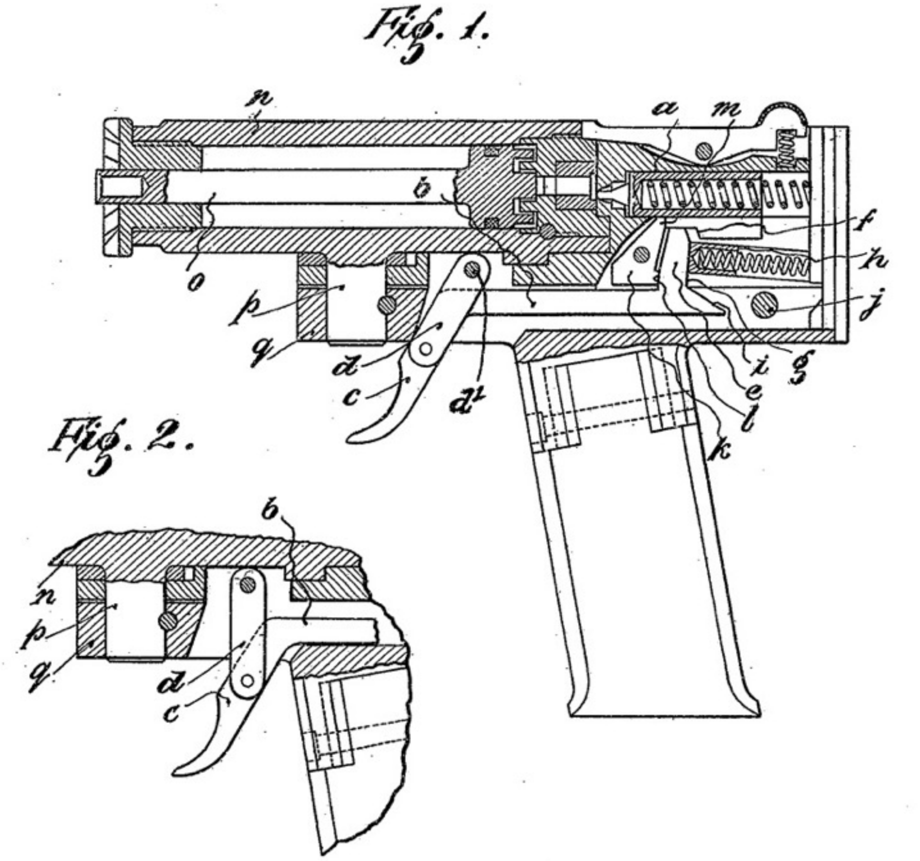

Figure 27: *CASH model B 1929 Captive Bolt Pistol Patent Drawing*

Figure 28: *CASH model B Captive Bolt Pistol (Author's collection)*

1.1.10 EXIT FLAMELESS HUMANE KILLER 1930

The plight of pit ponies came under scrutiny in the early 1900's as well as slaughter animals; the issue with humane killing of injured ponies down coal mines with mechanical tools was the ignition of any natural gas when operating the equipment. The Exit Flameless Humane Killer (Figure 29) was designed by William Harold Brailsford Stevens to overcome these issues and became the only weapon approved by the Board of Trade, for the dispatch of pit ponies underground, under the Explosives in Coal Mines (Horse Killers) Order 1931, made under section 61 of the Coal Mines Act 1911 (the pit ponies charter). The Exit Flameless Humane Killer was a captive bolt powered by a 0.320” calibre blank cartridge, the gases formed by the discharge of the cartridge were confined in a hermetically-sealed and pressure tight exhaust chamber contained within the handle. The killer included a safety-cap over the breech, so designed that the cartridge could not be fired whilst the appliance was incompletely assembled. (Figure 30)

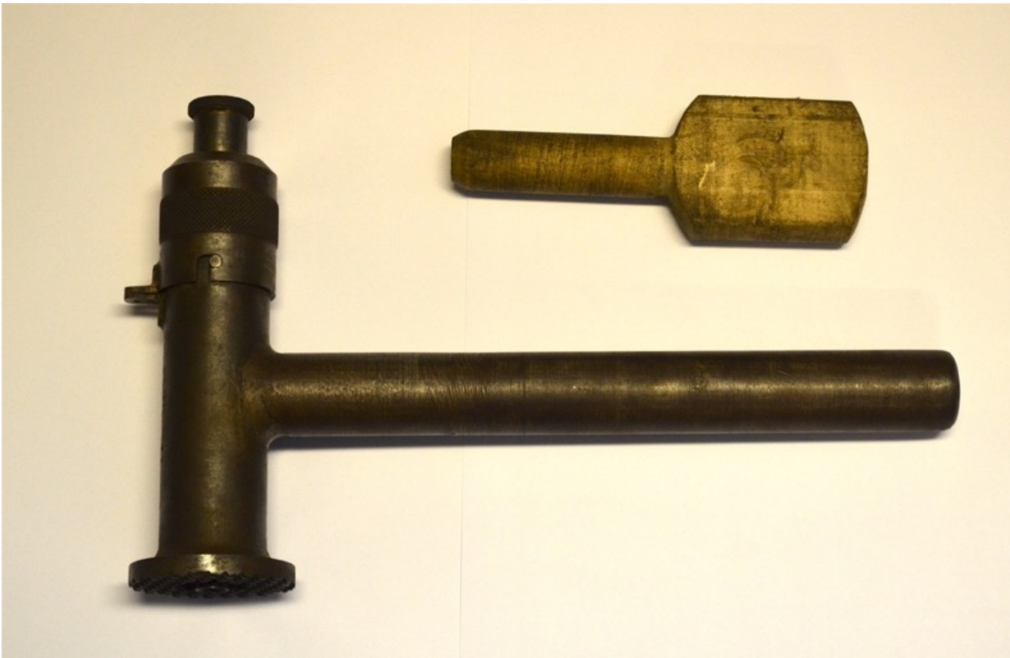

Figure 29*: EXIT Captive Bolt Device (Author’s collection)*

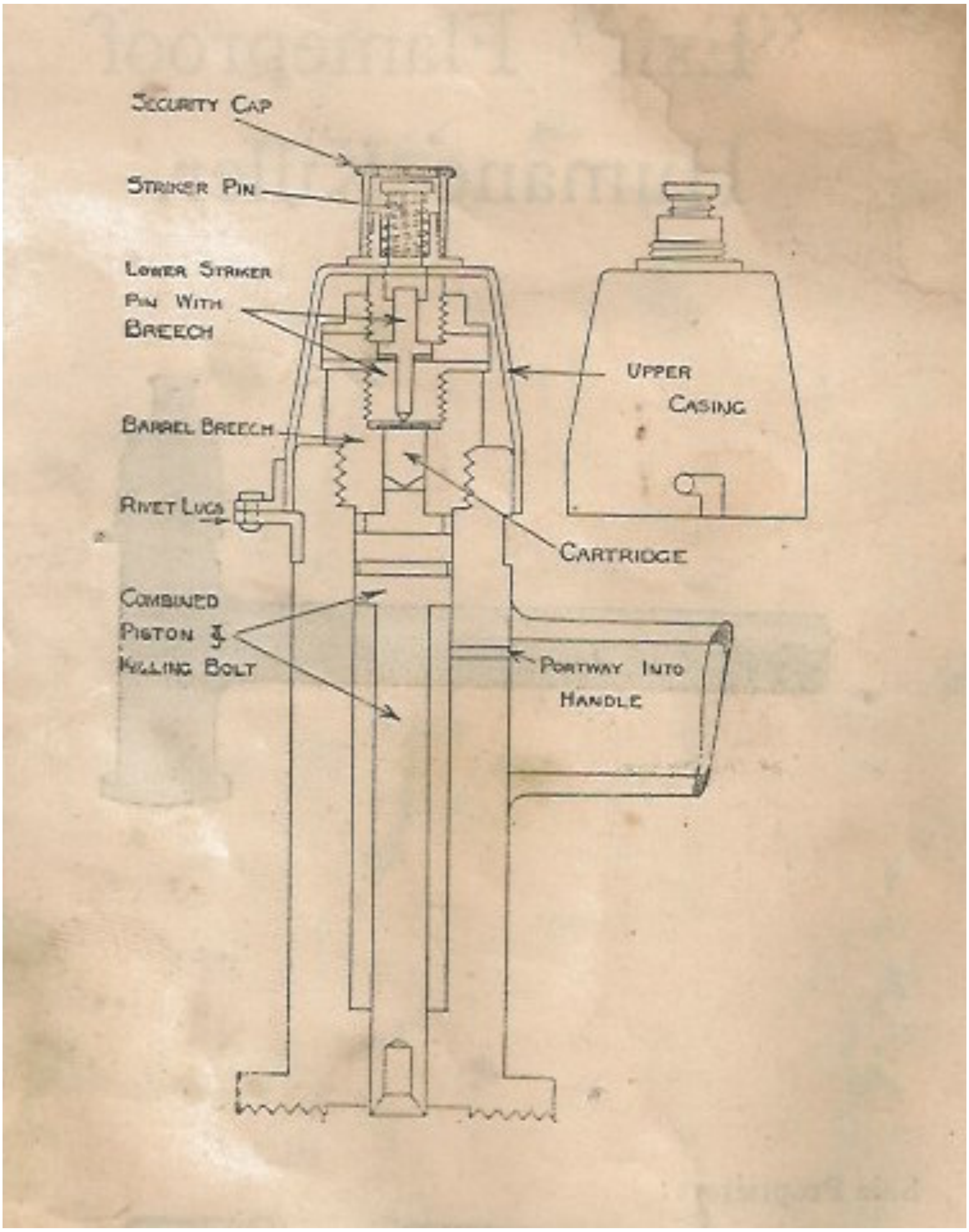

Figure 30*: EXIT Captive Bolt Device instruction manual (Author's collection)*

1.1.11 Accles and Shelvoke CASH X Penetrating Captive Bolt Pistol

Developed in 1943, the CASH X (Figure 31) replaced the CASH B pistol (Figure 28). The design removed the pivoting barrel to load of the CASH B and relied upon a grease collar to seal and lubricate the penetrating bolt. The cartridge boxes contained a pad of grease (Figure 32) so that this grease collar was replaced every 50 shots. Anecdotal evidence at the time suggested that slaughtermen would use a strip of porcine fat to achieve a similar effect.

Figure 31*: CASH X Captive Bolt Pistol (Author's collection)*

Figure 32: *CASH X Captive Bolt Pistol 50 Cartridge box with silver grease pack (Author's collection)*

1.1.12 Accles and Shelvoke CASH Special captive bolt pistol

In 1968 the Accles and Shelvoke CASH X was replace by the CASH Special Pistol (Figure 33). This pistol had a more ergonomic design and introduced the use of recuperator sleeves also known as 'buffers' that compress maximally on firing and then expand when the gas pressure is released through a vent hole in the barrel so that their expansion removes the bolt from the head back into the breech. The wood handle was also replaced with plastic for hygiene reasons. The CASH special was originally produced to accommodate 0.22" cartridges but was later developed to take 0.25" calibre cartridges.

***Figure 33**: CASH Special Captive Bolt Pistol (Author's collection)*

1.2 Current Understanding of the Use of Captive Bolt Devices

Misconceptions and meat industry myths have surrounded the use of captive bolt devices for the pre-slaughter stunning of meat animals, some used by the meat industry in the United Kingdom to delay their use under legislation; such as the fear that a shot animal will not bleed as completely as a non-shot animal, which has since been disproved by research including Anil et al., 2006. The use of captive bolt devices has been researched over the years and reviewed by Terlouw et al. (2006a,b). It has been established that it is the transfer of kinetic energy from the bolt to the cranium that produces the differential acceleration and also pressure wave induction through the brain (hydraulic and hydrostatic shock) leading to disturbance of blood flow (Posner et al., 2008), depolarisation of neurons within the cerebral hemispheres (Gregory, 1998; Posner et al., 2008), possible brain herniation through the tentorium (Carey, 1995) leading to compression of brain areas such as the medulla and brain stem.

Penetrating captive bolts differ from non-penetration only as the subsequent penetration of the bolt produces further damage to the brain in an attempt to prevent recovery from the concussion. This damage is a combination of mechanical damage of the bolt entry with cranial bone fragments (Gibson et al, 2012) and increased hydrostatic and hydraulic shock in conjunction with a temporary wound channel created by the passage of the bolt through cerebral tissue (Karger, 1995; Puschel and Braun, 2009)

1.2.1 Gun Types

All modern captive bolt guns operate with a similar system, the rapid projection of a bolt or piston onto the cranium of the animal to be stunned. That impact may be followed by penetration into the cranial cavity in an attempt to prevent recovery. There are six basic modern captive bolt designs, two performance types; penetrating, non-penetrating, two activation types; trigger fired (Figure 34), contact fired (Figure 35), and two gas source types; cartridge powered or pneumatic powered. These are commercially available devices, the usage choice of which is dependent on the abattoir, for example they may choose to use a cartridge powered contact firing penetrating captive bolt or pneumatic, the latter tending to be used in larger throughput plants, especially in the USA. Whichever system is used the effect on the animal is to produce a concussed state. Although successful in producing a concussion in mature cattle, the use of non-penetrating captive bolt devices is limited to ruminants under 10Kg liveweight by the current European Legislation (EC1099/2009 on the protection of animals at the time of killing).

***Figure 34**. Example of a cartridge powered, trigger-fired penetrating captive bolt device (Split model)*

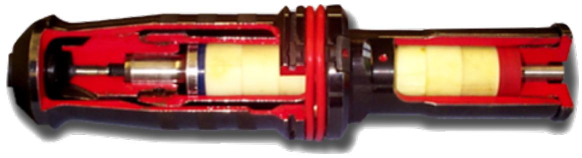

***Figure 35**. Example of a cartridge powered, contact-fired penetrating captive bolt device (Split model)*

1.3 Introduction to the on-farm euthanasia of neonate animals

The humane slaughter of animals within an abattoir environment has been subject to decades of research, scrutiny and legislation. However, the on-farm dispatch of neonates that require euthanasia for disease control, production efficiencies or abnormality, has been largely overlooked. As modern production systems present mass birthing within a controlled environment, stock persons can be faced with a decision to either leave ‘poor’ neonates with the mother in the hope of improvement, access veterinary intervention, or humanely dispatch the animal. However, the euthanasia of neonate farm animals has relied on the husbandry practices of the producers and tended toward the application of manual blunt force trauma either through direct application to the head (Figure 36) or impact of the head with a wall by swinging the neonate by the rear legs (Figure 37) (*HSA 1997*).

Figure 36*. Using a hammer as a blunt force trauma device for euthanasia (Courtesy of HSA)*

Figure 37 *Using a wall as a blunt force device for euthanasia (Courtesy of HSA)*

Both methods raise welfare concerns including efficacy, reproducibility, training of personnel to perform the action and the fact that stockpersons do not like undertaking the action unless there is no other option, leading to some animals that should be euthanized being left to suffer, for longer than necessary.

Lamb mortality in Wales is estimated as being approximately 12 per cent, with a proportion of these being due to abnormality (4%), lamb too small (6%), disease (9%), and other (18%) *(HCC, 2016).* Given that the 2017 Defra census estimating approximately 17 million ewes present within the United Kingdom *(SHAWG 2018)*, the majority of which were are likely to have twins, this extrapolates to approximately 754,000 lambs possibly requiring dispatch each year within the United Kingdom. Similar figures for pigs suggest that 1 in 12 piglets may require dispatch before 26 days of age (AHDB, 2015).

1.4 Objectives of this thesis

1.4.1 On-farm euthanasia of neonate animals

The first part of this thesis describes the work undertaken to validate the use of non-penetrating captive bolt devices to provide a reproducible stun/kill in piglets, lamb and goats requiring dispatch due to production efficiencies, disease or other reason. The first two papers examine the use of a Bock Industries Zephyr EXL pneumatic powered non-penetrating captive bolt device for single application euthanasia of piglets and was prepared as information for Alberta Agriculture and Forestry, Canada. Funding for this project was provided through Growing Forward 2, a federal-provincial-territorial initiative.

The published papers three to five cover the research evaluating a commercially available, cartridge powered, non-penetrating captive bolt device to achieve an immediate stun/kill in piglets, lambs and kids and also to establish the correct shot position to ensure effective repeatability. This latter work was funded by the United Kingdom Department for Environment, Food and Rural Affairs (DEFRA) under project MH0150, Study to investigate humane killing methods for neonate livestock. A previous DEFRA study (MH0116) undertaken by the University of Bristol examined the performance of three devices and found the Accles and Shelvoke Small Animal tool to be the most effective in producing a stun/kill using behavioural assessments. The Small Animal Tool was developed at the University of Bristol in association with Accles and Shelvoke as a PhD project “The development of a novel device for humanely dispatching casualty poultry” (Hewitt, 2000).

1.4.2 Discussion of some terms used in this thesis and research papers for neonate euthanasia

The research methodology was designed to comply with the European Food Safety Authority (EFSA) Guidance on the assessment criteria for studies evaluating the effectiveness of stunning interventions regarding animal protection at the time of killing (EFSA 2013)

1.4.2.a The definition of death used in the neonate research

The Animals (Scientific Procedures) Act 1986 in the United Kingdom defines death as “permanent cessation of circulation or the destruction of its brain”. As the application of both methods for neonates is cranial, we are taking the latter definition of permanent brain destruction as the determination of death, and the behavioural indicators chosen for the field work are recognised brain stem reflexes whose absence indicates brain death. (EFSA, 2013)

1.4.2.b Stun and stun/kill

The European legislation on the protection of animals at the time of killing defines stunning as “Any intentionally induced process which causes the loss of consciousness and sensibility without pain, including any process resulting in instantaneous death” (EC1099/2009 Article 2(f), 2013). The European Food Safety Authority (EFSA, 2004) states that an animal can be ‘judged to be unconscious and insensible” if evoked electrical activity in the brain is abolished by the method applied. In the basic context of stunning and slaughter and in this thesis, a stun is considered a temporary state of brain dysfunction from which the animal has the potential to recover unless a further intervention is applied such as exsanguination, anoxia or induced cardiac arrest.

A stun/kill is defined by EFSA (2004) as a method that induces unconsciousness and death either simultaneously or sequentially. The devices trialed in this research were designed as single application euthanasia devices, the experiments were therefore designed to assess a successful stun/kill of the neonate, and a purely stunned state would be considered a failure of the device or the positioning of the device in the context of the research.

1.4.2.c The use of Visual Evoked Potentials in the neonate research

The use of evoked potentials, recording the brain response to a repeating stimulus is used to objectively determine the patency of specific pathways within the nervous system and brain, the abolition of a response to the stimulus being considered as an unequivocal indicator of the loss of brain responsiveness (Guerit, 1999, EFSA, 2004). The external stimuli have traditionally been either visual (VEP), auditory (AEP) or somatosensory (SEP), the latter requiring pulsed electrical stimulation of a peripheral nerve.

Visual evoked potentials were chosen as the method used to assess the efficacy of the mechanical non-penetrating captive bolt device rather than somatosensory evoked potentials as there were concerns that the application could disrupt the brain stem thereby disrupting SEP impulses from reaching the brain. VEP’s were also decided upon as their abolition is indicative of the brain’s incapacity to receive and process external stimuli (EFSA, 2013).

1.4.2.d The use of behavioural indicators of brain dysfunction of neonates

The use of behavioural indicators of brain dysfunction were developed by comparing observed behaviours whilst recording brain activity within the laboratory setting to provide a method of field assessment. The indicators used are recognised as demonstrating either brain dysfunction preventing the processing of external stimuli, or indicative of the disruption or destruction of specific neural pathways indicating the brain death of the neonate. (Terlouw *et al,.* 2016a EUWelNet 2013). The brain reflexes chosen for examination in this research were rhythmic breathing, corneal reflex and response to pain. Although considered a method with high specificity, pupillary response to light was discounted as a method in this research as it was a method considered unlikely to be carried out in a production setting by operatives.

Rhythmic breathing - The act of (respiration) is controlled by groups of neurons within the medulla oblongata that are stimulated by the reticular formation in the brain. (Terlouw *et al,.* 2016a) Therefore, following the application of blunt force trauma, an animal that is breathing rhythmically may be unconscious - but an animal that is not breathing rhythmically is either unconscious, dying or dead (Terlouw *et al,.* 2016b)

No corneal reflex – The absence of a positive corneal reflex, the neural circuit of which crosses the reticular formation, is indicative of the disruption of the reticular formation and hence the ability of the brain to respond to external stimuli. As with rhythmic breathing, an animal with a positive reflex may be unconscious, but an animal with a negative reflex is either stunned, dying or dead. (Terlouw *et al,.* 2016b)

Response to painful stimuli – The main purpose of any stun or stun/kill method is to ensure the subject animal does not feel pain during any subsequent operations

(EFSA 2013). The subject neonates were tested post application for absence of a pain response via the insertion of a hypodermic needle into the nasal septum, with a positive reflex (head withdrawal) being considered a failure of the method.

1.4.2.e Post application movement of the neonate

The issue of post death movement was a concern for producers, especially those pig producers in the United States of America who routinely euthanised neonates by hypercapnia via the application of carbon dioxide in a closed container and therefore tended not to see post stun/kill movement. Pigs especially are known for a very short tonic period succeeded by a violent and extended clonic period following mechanical stunning techniques (EFSA 2004) and, as discussed in in the papers, this can be unsettling to the operative or bystanders (Mort et al 2008; Whiting & Marion, 2011; Matthis, 2004).

Post stun movement will occur in all three species trialed as part of the research of the euthanasia of neonates and is indicative of the loss of brain control of spinal reflexes (Gregory, 1993) the intensity and duration of post application movement was recorded and compared to laboratory results to provide producers with assurance of the efficacy of the method and to provide training material to enable this.

1.4.3 The Use of Captive Bolts on Animals

Chapter Four presents two areas of research undertaken examining factors affecting the successful application of captive bolt devices in a commercial setting. Paper Six is the product of work initialised by the author to ascertain causes of secondary and tertiary stun attempts in an effort to reduce their occurrence though the provision of educational material. Paper seven is an examination of the variation in cartridge performance. A key component of the mechanical stunning device is the propellant for the bolt, either pneumatic or blank cartridge. As the power produced by the propellent determines the velocity (and hence the kinetic energy (E_K) to achieve an effective stun (E_K = ½ mass x bolt velocity^2)), any variation in output will have a detrimental effect on the ability of the device to stun. Despite this importance, there has been little examination of this key component. Recent work by Gibson et al (2015) examined the performance of captive bolt devices and alluded to variation possibly being due to cartridges, and Gregory et al (2017) discussed sound output as a method of determining low velocity shots. Work undertaken for the euthanasia of neonates (Chapter Three, Papers 3-5) found variation in cartridge performance that led to Paper Seven, which is considered the first in depth examination of cartridges themselves and has led to the development of an in-vivo velocimeter which will allow accurate measurement of each shot applied. This study demonstrated that there was a variation in velocity ranging from 35.7 m/s to 62.9 m/s within the same batch of cartridges, which has the effect of the higher value having three times the kinetic energy of the lower value cartridge.

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Chapter Two

On farm euthanasia of neonate animals – Evaluation of the Bock industries Zephyr EXL Non-penetrating Captive Bolt Device

2.1 Candidate input.

Paper One and Paper Two:

This research used the abolition of Visual Evoked Potentials (VEP) as a method of determining loss of residual consciousness following a single shot with the Bock Industries Zephyr EXL. After each shot was administered the physical response of the animal was recorded in conjunction with brain activity to provide a subjective determination of brain death which could be later used ‘in the field’. Andrew Grist was involved in the initial discussions into this research concept and contributed to the experimental design of this project in conjunction with the other authors and also assisted in the analysis of the VEP traces to determine efficacy of the shot. Andrew Grist performed the postmortem examination of the 62 piglets for Paper One, conducted the postmortem examination of the 207 piglet heads in situ at the farm in Texas and took the photographs which were later assessed using a brain haemorrhage scoring system he adapted from Sharpe et al (2014). Andrew Grist created and recorded all the data in an XL spreadsheet and assisted in the statistical analysis of the data with supervisors. Andrew Grist wrote the paper detailing the results with comments provided by the other authors and prepared the figures for publication. As part of the writing of the paper Andrew Grist researched the cause of agonal breathing in cortically brain-dead animals, as this was noted in 15% of piglets post shot, that displayed no VEP. This agonal breathing was considered a possible concern for producers using the device as they may consider the shot ineffective and this therefore required discussion and clarification. Andrew Grist dealt with reviewers’ comments and prepared the final version of the paper for publication.

2.2 PAPER ONE

Humane Euthanasia of Neonates I: Validation of the Effectiveness of the Zephyr EXL Non-Penetrating Captive Bolt Euthanasia System on Neonate Piglets up to 10.9 kg Liveweight. Grist, A., Murrell, J.C. McKinstry, J.L., Knowles, T.G and Wotton, S.B.

Animal Welfare 2017, 26: 111-120 ISSN 0962-7286 doi: 10.7120/09627286.26.1.111

Humane Euthanasia of Neonates I: Validation of the Effectiveness of the Zephyr EXL Non-Penetrating Captive Bolt Euthanasia System on Neonate Piglets up to 10.9 kg Liveweight

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Abstract

To determine if mechanical blunt force trauma using a non-penetrating captive bolt was a viable method of producing an immediate stun/kill in neonate piglets (*Sus scrofa domesticus)* as an alternative to manual blunt force trauma, piglets (n=60) were acquired from a local producer and allocated to one of 5 weight ranges - Birth weight to 3 kg (n = 12), 3 to 5 kg (n = 11), 5 to 7 kg (n = 13), 7 to 9 kg (n = 13) and 9 to 11 kg (n = 11). These piglets, with an average liveweight of 6.1 kg, were anaesthetized and electroencephalogram (EEG) recording electrodes inserted subdermally over the right cranium to allow recording of Visual Evoked Potentials (VEPs). Following recording of baseline VEPs in the anaesthetized state the piglet was shot once in the frontal-parietal position with a Bock Industries Zephyr EXL non-penetrating captive bolt powered by 120 psi air pressure. Movement scoring, behavioural indices of loss of brain function and VEPs were monitored throughout. VEPs were lost immediately in all piglets shot when the head was resting on a hard surface. This experiment demonstrates that mechanical blunt force trauma using a single shot non-penetrating captive bolt, such as the Zephyr EXL, provides for an immediate stun kill in neonate piglets up to 10.9 kg liveweight. This immediacy of action, combined with reproducible effects will improve the welfare of piglets to be

subjected to on-farm euthanasia due to disease, ill-thrift or other commercial concerns.

Keywords: Animal welfare, Captive Bolt, Euthanasia, Mechanical Stunning, Piglet, Visual Evoked Potentials

Introduction

Modern pig production has an inherent requirement for the humane euthanasia of neonate piglets for various reasons including herd productivity, disease and under performance. In the United Kingdom pre-weaning mortality averages 14.18% (Agriculture and Horticulture Development Board Report 2015) indicating that one in twelve piglets in a litter may require dispatch before the average weaning age of 26 days (average piglet weight 7 kg). The traditional method of dispatch is manual blunt force trauma (MBFT), either through holding the piglet by the hind-legs and hitting the head against a hard object or using some form of blunt force trauma such as a 'priest' (a heavy ended baton also known as a gamekeeper's or poacher's priest) or a hammer. Manual blunt force trauma as a humane method of euthanasia has several issues; firstly it relies on the ability of the operator to successfully perform the action, secondly the effects may not be reproducible and thirdly stockmen do not like performing the operation unless the animal appears ill and the method of euthanasia was perceived as being less painful to the animal (Mort et al 2008; Whiting & Marion, 2011; Matthis, 2004). Mechanical killing via blunt force trauma using a non-penetrating captive bolt device has the advantage of reproducibility, less reliance on operator ability and with training, including the identification of post mortem movement that indicates an effective stun/kill, enhanced operator acceptability.

Non-penetrative mechanical stunning relies on imparting kinetic energy to the cranium to produce concussive effects within the brain, based on the velocity of the impact rather than the mass of the object (Daly et al 1987). The concussion produced by this impact is often associated with both haemorrhaging at the impact site ('coup') and further haemorrhaging opposite the impact site ('contra-coup') (Ommaya et al 1971). This is due to the rotational and differential acceleration of the brain within the cranium (Ommaya & Gennarelli, 1974). Shearing forces are produced within the brain by the pressure waves producing vacuolation (Finnie, 1995), disruption of synaptic transmission (Gregory, 1998) and depolarisation of neurons away from the impact site (Somjen, 2001). Shaw (2002) also discusses the effects of sudden change in intracranial volume, brain compression and pressure waves following compression of the skull, with the pressure waves terminating at the brainstem and cranio-cervical junction. The most common cause of death following brain injury is subdural haemorrhage due to direct injury to the cortical arteries and veins by the object, contusion and pulping of the cerebrum, or tearing veins that bridge the subdural space between the brain surface and the dural sinuses (Millman 2010).

There were initial concerns that the incomplete sutures in the newborn piglet that provide for cranial deformation during parturition may provide a form of elastic protection from the effect of Blunt Force Trauma (BFT), in effect absorbing the blow. Previous studies (DEFRA MH0116) found that with a non-penetrating captive bolt (NPCB) the skull development of the neonate piglet is sufficient for the transfer of kinetic energy to the brain to produce a stun-kill. Research by Armstead (1999) also demonstrated that newborn piglets were particularly sensitive to brain injury.

A study to assess the effectiveness of a NPCB for euthanasia of suckling and weaned piglets using the Bock Industries Zephyr E pneumatic, non-penetrating, captive bolt was undertaken by the University of Guelph. This study used visual signs of sensibility and behavioural indicators including loss of rhythmic breathing, corneal reflex and response to painful stimuli to assess the effectiveness of the stun combined with post mortem examination of the head to assess skull and brain damage following a two or three shot technique (Casey-Trott et al 2013, Casey-Trott et al 2014). Following this research Bock Industries upgraded the Zephyr E to the Zephyr EXL which has a higher velocity, when operated at 120 psi, than the Zephyr E and hence develops a higher kinetic energy (27.7 J *c.f.* 20 J) (Personal communication, Lines 2015) to allow a single shot technique to be applied.
This current study sought to evaluate the effectiveness of the Zephyr EXL on neonatal piglets (n = 60) using the loss of VEPs as an indicator of cortical brain death (Gregory & Wotton, 1984: Guerit, 1999) followed by measurements of post stun movement, postmortem examination of fracture patterns and macroscopic examination of the brain.

Materials and Methods

Zephyr EXL Velocity

The Zephyr EXL velocity was measured by two methods to provide evidence of the velocity and hence kinetic energy (KE = $\frac{1}{2}mv^2$ where m = mass of projectile and v = velocity) produced by the non-penetrating captive bolt to give a guideline figure for any future recommendations. One velocity measurement was assessed by the manufacturer (Bock Industries, PA, USA); the Zephyr-EXL was hose connected (20

ft) to a 120 psi air pressure supply and mechanically fastened to a granite table with the bolt firing in the horizontal position. Using high speed (10 kHz) analog videography (Fastcam SA1.1, Proton, San Diego, CA, USA) combined with custom digitizing frame analysis software (Matlab, Mathworks, Torrance CA, USA) to directly calculate Zephyr-EXL bolt velocity as a function of bolt displacement. Based on averaging of three trials, the maximum velocity was 27.4 m/s ±0.1 m/s (26 J).
These figures were confirmed by bench testing the device at 6 to 8.1 bar (87 to 117 psi) and a prediction of its performance at 120 psi was made. Before firing, the apex of the percussive head cone is retracted 29 mm from the contact position, within the barrel. The bolt is free to travel to a point 30 mm beyond the contact position without any reciprocating buffers i.e. free-flight.
The moving components of the Zephyr EXL in normal use comprise a steel bolt and a plastic hammer head weighing a total of 62 g. The device was tested with combined bolt, projectile holder and projectile masses of 69 and 99 g. Maximum bolt velocity during the stroke was measured. The bolt energies at the higher bolt mass differed from the lower mass by less than 4% despite the 43% change in mass. Therefore the energies of the bolt at the lower test mass (69 g) were taken to be the same as the energy in use (mass 62 g).

Bolt energies were found to be 20.6 J at 6 bar (87 psi) and 27.2 J at 8.1 bar (117 psi) indicating that the energy at 120 psi would be expected to be 27.7 J. (Personal communication, Lines, 2015)

Experimental Animals

All procedures were carried out in the University of Bristol, School of Veterinary Sciences in the United Kingdom (UK) under the provisions of the Animals (Scientific Procedures) Act 1986 and with the approval of the University of Bristol's Ethical Review Process.

Healthy piglets were purchased from a local farm (n = 62) and assigned to one of 5 weight ranges – Birth weight to 3 kg, 3 to 5 kg, 5 to 7 kg, 7 to 9 kg and 9 to 11 kg; the average liveweight of the piglets in this study was 6.1 kg. Two of the piglets (numbers 5 and 6) were not used as they were found to be over the upper weight range of the trial. These piglets were anaesthetised with sevoflurane (SevoFlo, Abbott Animal Health, UK) vaporised in oxygen delivered via an Ayre's T piece breathing circuit. In order to induce anaesthesia piglets were gently restrained and an appropriately sized close fitting face-mask (Ace Veterinary Supplies Ltd, UK) was attached to the breathing circuit and placed over the muzzle. Sevoflurane was delivered to the facemask at a dialled vaporiser setting of 8%, using an oxygen flow rate of 3 l min^{-1}. Following induction of anaesthesia, signalled by loss of voluntary movement, recumbency and loss of the palpebral reflex the concentration of sevoflurane was reduced to 2.5%. Anaesthesia was maintained with this concentration of sevoflurane using the facemask and breathing circuit for the duration of the procedure. The electrocardiogram was recorded immediately after induction of anaesthesia using three surface ECG electrodes attached to the right and left forefeet and left hind-foot of the piglet and a multi-parameter monitor (Datascope Passport 2, Mindray, DS USA).

Figure 1. Anaesthetised piglet with recording electrodes inserted for Visual Evoked Potential recording.

Three 13mm disposable sub-dermal needles (SD51 - Unimed Electrode Supplies, UK) were inserted subcutaneously into the head of the animal according to methods used for sheep and pigs (Gregory & Wotton 1983; Wotton & Gregory, 1986). The negative electrode was placed 0.8 to 1.4 cm rostral to the lamboid suture; the earth electrode 1.5 cm rostral to the negative electrode and the positive 1.5 cm rostral to the earth electrode level with the rear canthus of the eye (Wotton & Gregory 1986). Following epidural implantation the left eye of the animal was taped open to expose the pupils. (Figure 1)

Visual evoked potential recording

The EEG electrodes were connected to a DAM 50 differential amplifier (World Precision instruments, FL, USA) before recording at a sampling frequency of 1024 Hz using Powerlab 4/35 (ADinstruments, UK). The band pass filter was between 0.1 and 100 Hz and the gain was set at 100. The scope software was set up to run initially without the light shining on the pig and no responses were seen allowing the conclusion that the VEPs that were recorded were responses to the visual stimulus rather than artificial synchronized responses. Visual evoked potentials (VEP's) were recorded with potentials being triggered and powered by an SLE Photic Stimulator at 2 flashes per second under normal lighting conditions. All epochs were recorded and stored using Scope4 software (ADInstruments, UK) which records and analyses signals that are time locked to the photic stimulus, and allows averaging of repetitive signals time locked to a stimulus to give an overall average waveform from a number of stimulus repetitions. Each waveform post stun was an average of 16 epochs of 200 ms duration recorded at a stimulus rate of 2 flashes per sec, i.e. over an 8 second period. The following VEP was analysed over the subsequent 16 epochs. This process continued for 64 epochs post stun to ensure that VERs were lost. The pre-stun averages were reviewed immediately to verify that there was a repeatable VEP in all animals (similar to that shown in Figure 2).

At the end of EEG data collection, following confirmation of brain death, administration of sevoflurane and oxygen was stopped.

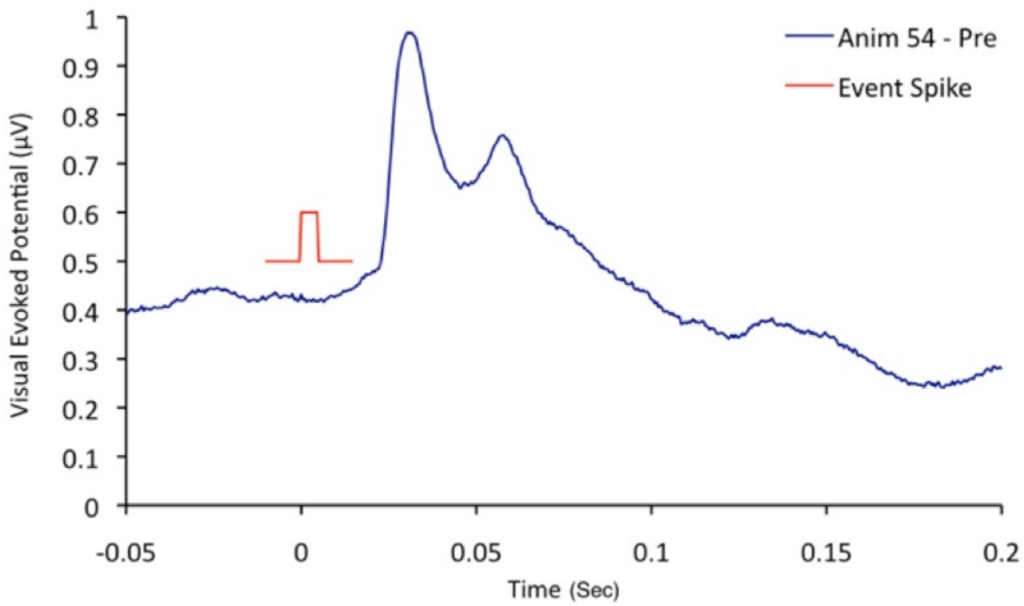

Figure 2: An example of a prestun VEP (Piglet 54) illustrating a typical response following photic stimulation at time 0, indicating the visual pathway is functional.

Once the pre-recordings were completed the animals' heads were held manually against the operating table and shot once using the Bock Industries Zephyr EXL pneumatic captive bolt gun in the parietal position by a senior researcher. The gun was fired using compressed air at 120 psi delivered by a Scheppach HC51 oil lubricated 50 Litre air compressor (Scheppach, DE)

VEPs were continuously recorded for 3 minutes post-shot to ensure they did not return i.e. to verify the death of the animal. Following stunning, subjective evaluations were made on the effectiveness of the stun, i.e. loss of brain stem reflexes such as rhythmic breathing, loss of corneal reflex (no response to corneal stimulus) and palpebral reflex (no response to stimulation of the eyelid). These observations were made continuously throughout the 3-minute recording period looking for any return of rhythmic breathing or agonal (spinal induced) gasping. The level of post-stun movement (enhanced spinal reflex activity) was subjectively assessed and recorded on a scale of 0 to 3 based on the descriptors in Table 1.

Score	Descriptor	Description
0	No activity	Very little movement.
1	Mild activity	Some mild uncontrolled physical movement of limbs.
2	Moderate activity	Considerable uncontrolled physical movement of the limbs.
3	Severe	Gross uncontrolled physical movement

Table 1: Subjective scoring system used to assess post-stun/kill movement based on level of spinal reflex activity, ranging from 0 (no activity post-stun) to 3 (Gross uncontrolled physical movement)

Once completed, the VEP epochs were stored and analysed at a later date using the Scope4 software. Sequences of 16 responses to photic stimulation were averaged together both pre- and post-stun. The post-stun averages were continued over a duration of 360 epochs (3mins) to identify the presence or absence of post-shot evoked potentials.

Post mortem analysis

Post mortem examination of the heads was carried out. After photographing the intact head using a Nikon D5100 digital camera, the skin from the head was removed following a T incision cranial to the shoulders and extending forward to the snout. The impact site was photographed before removal of any haematoma and the periosteum to expose fracture lines extending from the impact site. Photographs were taken of the fracture patterns to allow for later comparison. The heads were then hard frozen to facilitate sectioning on the medial plane for photography of cranial and brain lesions to be undertaken. The photographs of all the sagittal sections were assessed by two researchers without reference to age or weight group, with each sagittal section being scored for macroscopic damage to the brain with a scale adapted from Sharpe et al (2014) of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The results were discussed by the two researchers and scores moderated. The areas examined for macroscopic damage were the frontal, parietal and occipital cerebrum including the structure of the lateral ventricle. (Figure 3)

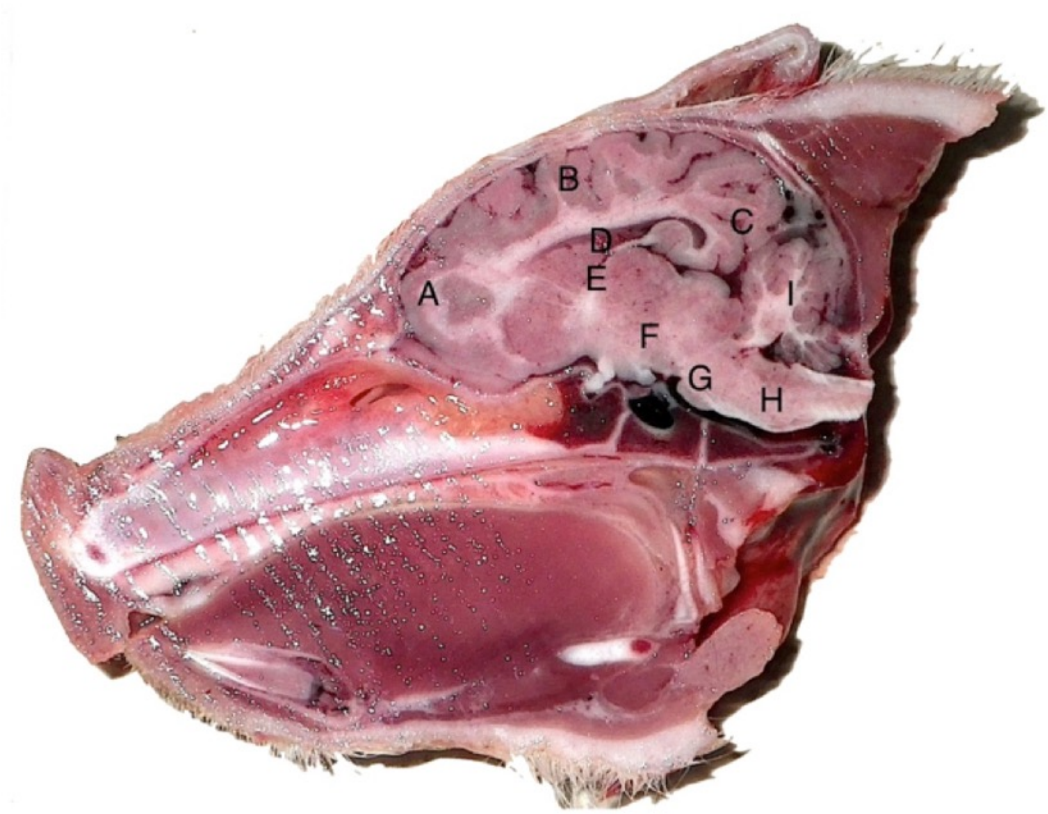

Figure 3. Sagittal section of unshot piglet head (died on farm) illustrating the areas examined for macroscopic damage. A-Frontal cerebrum, B-Parietal cerebrum, C-Occipital cerebrum, D-Lateral ventricle. These were scored on the basis of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. Areas E-I (Thalamus, midbrain, pons, medulla and cerebellum respectively) were assessed for presence or absence of ecchymosis.

Statistical Analysis

Below we present simple summary statistics broken down by weight group. Correlations between variables were investigated using Spearman's Rho, a non-parametric test of correlation. A Jonkheere-Terpstra test, a non-parametric test, was used to investigate whether there was an ordered effect of median piglet weight upon movement score. All statistical analyses were carried out using IBM SPSS Statistics (v23).

Results

Movement scores

The effect of piglet weight on movement score was analysed using a Jonkheere-Terpstra test for an ordered association with median weight within each movement score. The effect was significant with a standardised J-T statistic = -2.595, $P = 0.009$ (Figure 4). The analysis demonstrated that the median weight for movement score 0 was 10.3 kg, for score 1 the median piglet weight was 8.25 kg, score 2 the median piglet weight was 6.35 kg and for movement score 3 the median piglet weight was 5.5 kg.

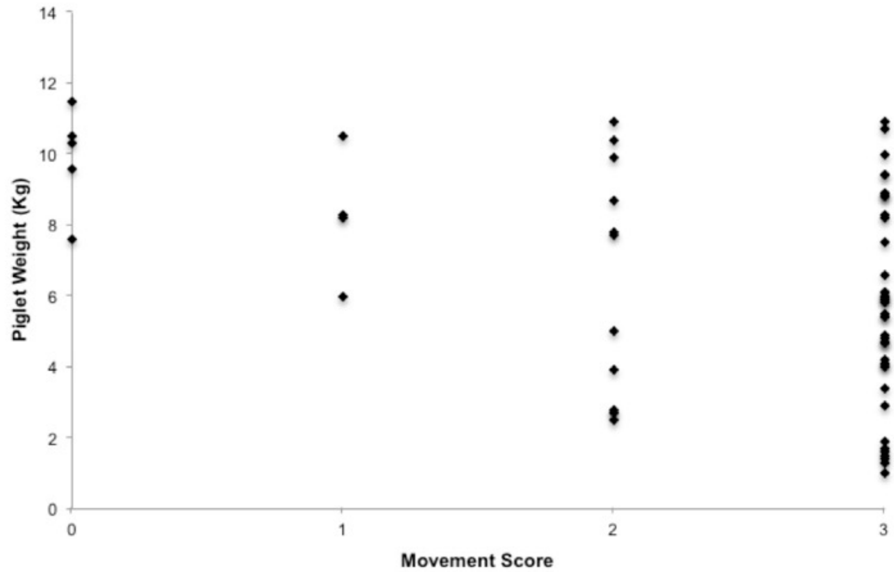

Figure 4 The effect of individual piglet weight on post-shot movement score. Where 0 denotes no uncontrolled physical activity post shot, 1 denotes mild uncontrolled physical activity post shot, 2 denotes moderate levels of uncontrolled physical activity post shot and 3 denotes severe uncontrolled physical activity post shot. Illustrating the results of the Jonkheere-Terpstra test that showed that heavier piglets displayed less movement post shot ($P = 0.009$).

Visual Evoked Potentials

Visual assessment of the VEP data showed that, of the 60 pigs shot, all were stunned and 59 (but see below) were killed by the blow, with immediate loss of VEPs post stun as shown in Table 2. There were no further signs of VEPs in the first 32 seconds (64 epochs) post stun (Figure 5). This abolition of VEPs remained throughout the 180 second recording period. All animals in groups Birth to 3 kg (n = 12), 3 to 5 kg (n = 11), 5 to 7 kg (n = 13) and 7 to 9 kg (n = 13) were killed immediately and showed no signs of recovery before death (Table 2), with the exception of the first piglet shot (piglet number 1, 9 to 11 kg group), which was stunned whilst the head was supported on a foam cushion (initially, to allow for differential acceleration of the brain within the cranium to produce severe concussion). Although demonstrating behavioural signs of being stunned, this animal showed VEPs throughout the 360 second recording period and required a secondary shot. Therefore, all subsequent animals were shot with their head manually supported against the solid surface of the operating table after which all were successfully, immediately killed.

Recording was undertaken for a period of 50 ms before and 200 ms after delivery of the stimulus, and there was no evidence of waveforms from the previous stimulus overlapping the next stimulus, as evidenced by the flat baseline period in the 50 ms recording before the stimulus.

Group	N	Weight (kg)			VEP's (0=abolished) (1=present)			Breathing (0=abolished) (1=present)			Movement Score See Table 1		
		Min	Max	Ave	Pre	Post	Return	Pre	Post	Agonal	Min	Max	Ave
0-3kg	12	0.98	2.89	2.00	12	0	0	12	0	5	2	3	2.67
3-5kg	11	2.37	4.90	4.31	11	0	0	11	0	0	2	3	2.91
5-7kg	13	5.00	6.55	8.83	13	0	0	13	0	0	1	3	2.85
7-9kg	13	7.50	8.90	8.28	13	0	0	13	0	1	0	3	2.23
9-11kg	11	9.36	10.90	10.26	11	1	0	11	1	3	0	3	2.00
Total	60			6.74	60	1	0	60	1	9			2.53
%						1.67			1.67	15.00			

Table 2: Results of the effect of the Zephyr EXL across piglet weight ranges on post shot Visual Evoked Potentials, breathing movements and spinal movement. One piglet from the 9 to 11 kg group was stunned but not killed, this was the only animal shot whilst its head was supported by a foam cushion, all others were subsequently placed against a hard surface.

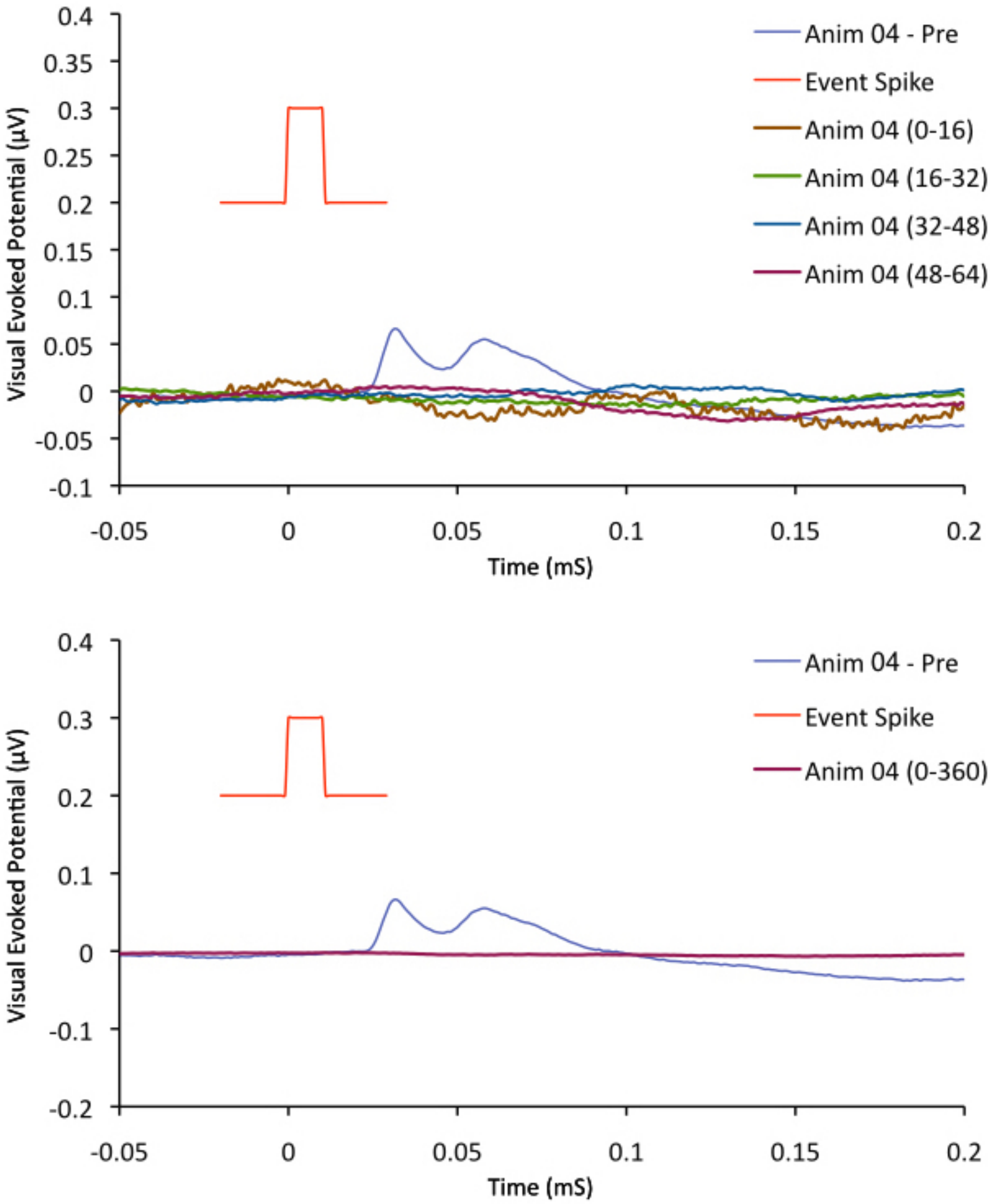

Figure 5. Examples of Visual Evoked Potentials pre- and post-stun for piglet number 4 demonstrating loss of response to the photic stimulation (time = 0) post-shot. The figures in brackets are the number of stimuli post shot (at 2 stimuli per sec), for the VEP's shown. The lower plot shows the averaged VEP over the complete 180 seconds post-shot displayed against the pre-shot averaged signal. The event spike shows one of the stimulus flashes that were presented at a rate of 2 stimuli per second over 180 seconds after the shot.

Post mortem analysis

Post mortem examination of the heads demonstrated a depressed fracture of the cranial plates corresponding to the impact footprint of the non-penetrating bolt, the depressed fracture being more defined in the heavier animals. In all weight ranges the most common factor was a fracture extending caudally from the impact point bisecting the nuchal crest, interparietal and occipital bones and terminating at the atlanto-occipital joint.

On sagittal section within all groups there was evidence of haemorrhage throughout the cranial cavity with blood evident within the corpus callosum and surrounding the medulla oblongata and within the cerebellum. In all cases the medial or frontal dorsal cerebrum showed damage after being crushed by bone plates, this can be seen by reference to differences with an unshot piglet head (Figures 6 and 7).

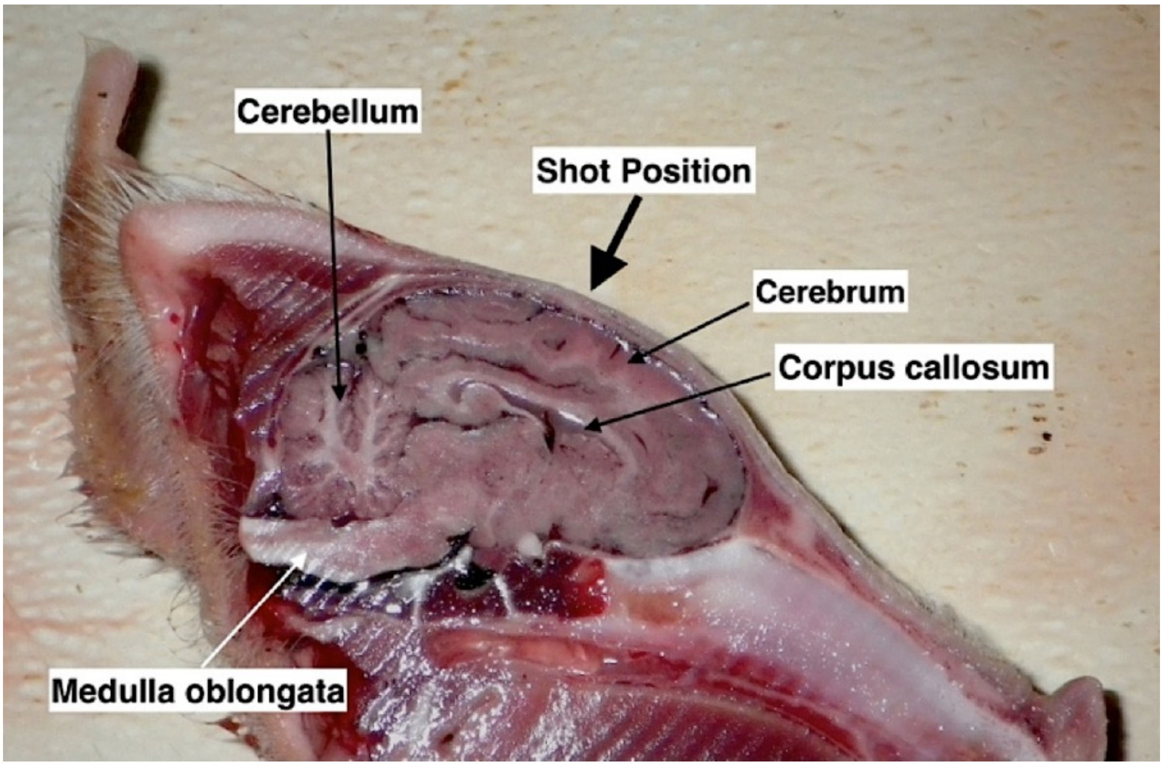

Figure 6. Sagittal section of an unshot piglet head, demonstrating the frontal shot position and the major brain structures affected examined after the shot.

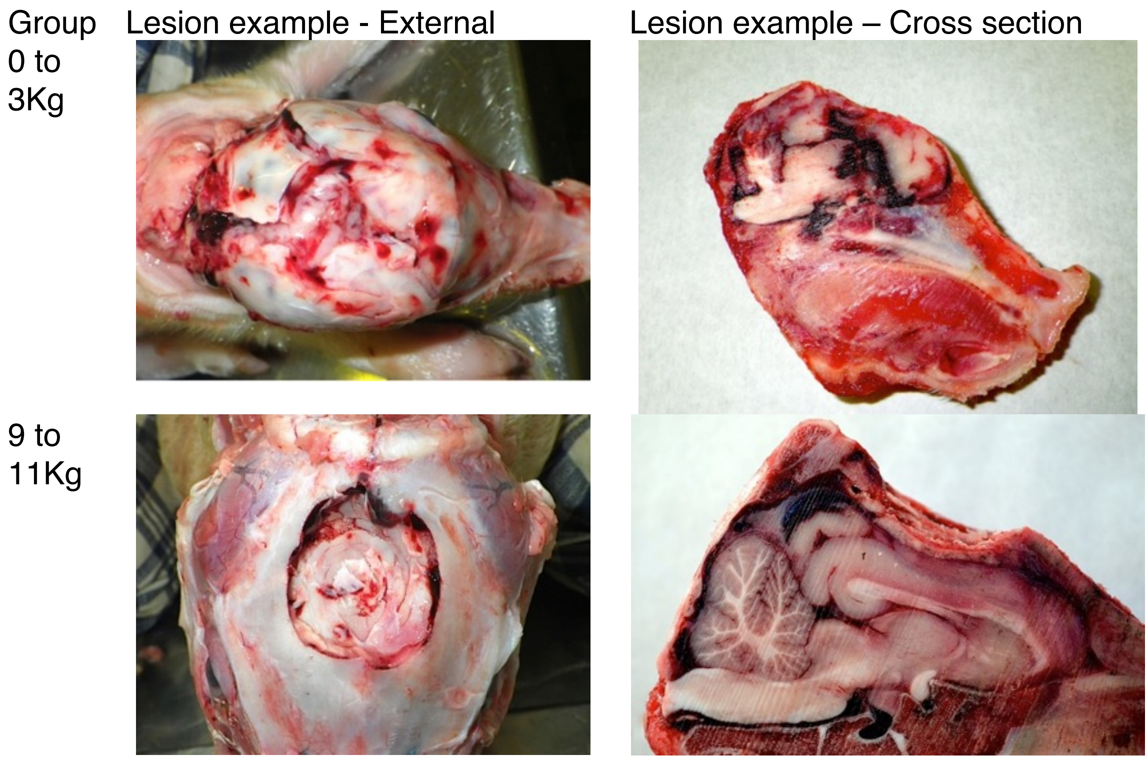

Figure 7: General fracture pattern (skin and periosteum removed) and traumatic injury to brain in sagittal section of piglets shot with the Zephyr EXL.

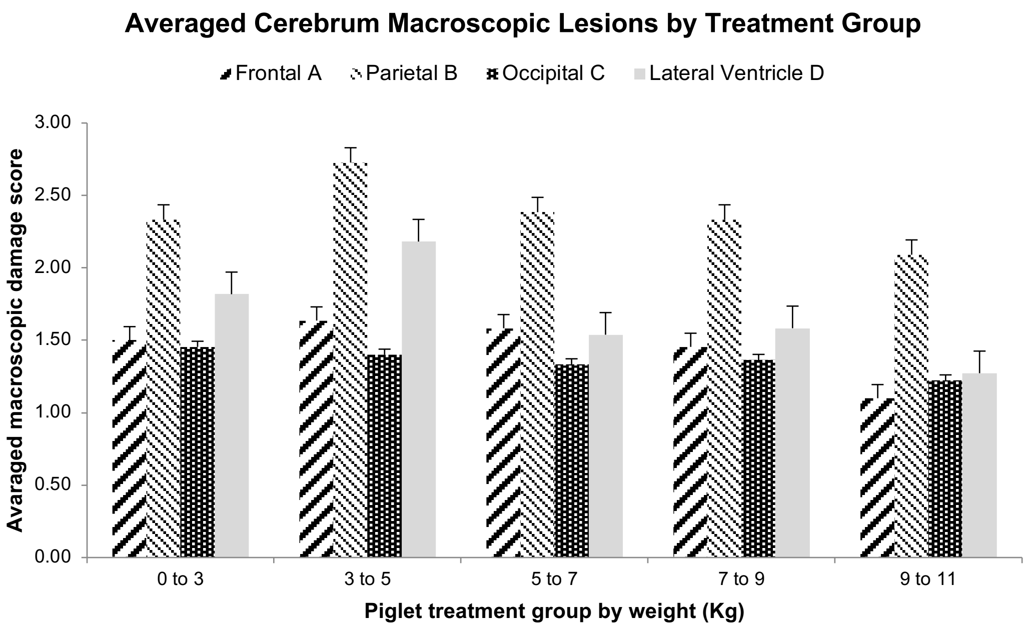

Figure 8: Averaged cerebrum macroscopic lesion scores by treatment group, demonstrating a reduction in the subjective macroscopic lesions found in sagittal sections of heads as the piglets age. Four areas of the brain examined for macroscopic damage, the frontal (A), Parietal (B) and Occipital (C) cerebrum and the lateral ventricle. These were scored on the basis of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area.

Figure 8 illustrates the results of the blind study of the sagittal sectioned heads. The scores were tested for an overall correlation between individual piglet weight and the score for each of the four areas using a Spearman rank (r_s) correlation test. There was no significant correlation for frontal A, parietal B gave a significant negative correlation (r_s = -0.274, df = 58, P = 0.034), occipital C, showed no significant correlation (r_s = -0.203, df = 52, P = 0.141) and lateral ventricle D gave a significant negative correlation (r_s = -0.390, df = 57, P = 0.002).

Discussion

General discussion

The use of the Zephyr EXL, as a euthanasia device for neonate piglets up to 10.9 kg, provides for immediate irreversible loss of visual evoked potentials and hence cortical brain death (Guerit, 1999) when the mechanical BFT is applied with the head resting on a hard surface. The macroscopic damage to the brain, both at the point of impact and contra-coup, suggests a level of unconsciousness and death due to the traumatic / concussive effect of the blow (Ommaya et al 1971). Duhaime et al (2000) found that in their model of focal brain injury the extent of brain damage following moderate scaled cortical impact increases with maturation and body weight, but did recognise that the findings may alter with severe mechanical trauma and the physiological stress imposed by other factors such as subdural haematoma or diffuse inertial injury. Armstead and Kurth (1994) found a greater cerebrovascular physiological instability in younger animals following fluid-percussion injury.

Skull density and suture development does not appear to affect the efficacy of the impact of the Zephyr EXL, possibly due to the level of applied kinetic energy and the shot position being on the parietal bone. The depressed fracture pattern was more organised in the larger animals, due in part to the increasing bending stiffness of the parietal bone with age (Baumer 2010, Powell, 2012). However, the efficacy of the BFT relies on the head being restrained on a hard surface. Piglet # 1 was stunned, but not killed, indicated by the presence of VEP's following the shot. This was the only piglet shot with its head restrained on a foam cushion to allow for a degree of cranial acceleration, the remaining piglets being shot with their head manually supported against the hard surface of the operating table. This suggests that, with piglets, the use of a non-penetrating captive bolt to administer BFT relies less on differential acceleration of the brain within the cranium, but more a high velocity impact producing deformation of cranial bones and pressure waves throughout the brain corresponding to theories presented by Shaw, 2002.

Movement post shot

Movement post shot is generated through enhanced spinal reflexes. The mechanical BFT so disrupts the function of the brain that the normal inhibitory influences, of the higher centres on the spinal cord, are lost before the spinal cord becomes exhausted and unresponsive. This loss of control by the higher centres over spinal reflexes results in an enhancement of their activity (Gregory, 1993). Thus, post shot convulsions can be produced at a spinal level and it may well be argued that they should be produced, as they are one of the indicators of brain dysfunction and hence an effective stun.

Agonal breathing

The presence of agonal breathing, spinal in origin and not rhythmic, was recorded in 9 (15%) of the piglets >3 minutes post shot. The absence of VEP's for these animals combined with an isoelectric EEG confirmed absence of cortical brain activity. Hayes et al (1988) found that concussive injury produced different effects depending on the distance from the site of impact, including depression and focal activation of brain regions. Similar movement phenomena have been attributed to activity in the spinal dorsal horn of brain dead human patients (Urasaki et al 1992). This suggests that the complex movements shown by brain dead humans may either reflect partial function in spinal neurons or represent the physiological potential of the intact isolated spinal cord. Spittler et al (2000) found that 10% of human brain dead patients exhibited various spinal automatisms, while Döşemeci et al reported 13.4%, and Saposnik et al (2000) placed the figure of spontaneous and reflex movement in brain dead patients (referred to as Heart Beat Cadavers, HBC) higher in their study at 39%. Wijdicks (1995) describes the possible reaction of spinal neurons in response to both changes in the plasma partial pressure of CO_2 (PCO_2) levels and pH following brain death stimulating respiratory potential. Saposnik (2009) reviewed historical reports of movement in HBC's from 1960 to 2007 and found reports of respiratory-like movements leading to the theory that hypoxia stimulates neurons in the spinal cord. Turmel (1991) described spinal reflex movements in an HBC manifesting once cerebrospinal shock had abated, determining that these represented isolated spinal cord physiological potential. Therefore the possible effect of cerebrospinal shock may explain the time delay between the application of BFT and the onset of agonal breathing movements in this current study. Saposnik et al (2005) found that movement was more common in HBC with intracerebral haemorrhage (51%) than anoxic–ishaemic encephalopathy (11%), the former condition being more accurate for cases of BFT in piglets. In this study it was hypothesized that the presence of agonal gasping was spinal in origin and possibly indicative of residual partial isolated spinal neuronal activity due to changes in the plasma partial pressure of CO_2 (PCO_2) levels and pH in a brain dead animal with a patent heartbeat.

Conclusions

The Bock Industries Zephyr EXL has sufficient velocity and kinetic energy to stun/kill neonate piglets up to 10.9 kg liveweight, producing immediate loss of Visual Evoked Potentials in all animals with their head resting on a hard surface. Post shot convulsions are encountered representing enhanced spinal reflexes as would be expected in a brain dysfunctional animal. Agonal gasping can be observed in a percentage of the animals but can be considered as indicative of partial brain stem function in an animal whose higher brain centre has been destroyed, as none of the animals demonstrated other brain stem reflexes following the application, including rhythmic breathing, corneal reflex or response to painful stimuli.

Animal Welfare Implications

This experiment demonstrates that mechanical blunt force trauma using a single shot non-penetrating captive bolt i.e. the Bock Industries Zephyr EXL provides for an immediate stun kill in neonate piglets up to 10.9 kg liveweight and hence a humane death. This immediate loss of cortical function, combined with reproducible effects will improve the welfare of piglets to be subjected to on-farm euthanasia due to disease, ill-thrift or commercial concerns. The technique with which the instrument is used is of utmost importance to ensure a successful and immediate death; the instrument has to be correctly positioned when the shot is fired and the piglet’s head retrained against a solid surface, as shown above.

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2.3 PAPER TWO

Humane euthanasia of neonates II: Field study of the effectiveness of the Zephyr EXL non-penetrating captive-bolt system for euthanasia of newborn piglets

Grist, A., Knowles, T.G. and Wotton, S.B

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Humane Euthanasia of Neonates II: Field study of the effectiveness of the Zephyr EXL Non-Penetrating Captive Bolt system for euthanasia of new-born piglets

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Abstract

A previous study demonstrated the effectiveness of the Bock Industries Zephyr EXL non-penetrating captive bolt, using the abolition of visual evoked potentials as a determination of brain death, in piglets in a laboratory. A second trial reported here, involved the field-testing of this device, on-farm, in a commercial setting. Two hundred and seven piglets (average dead weight =1.86 kg ±0.74) requiring dispatch under the farm's protocols were euthanized with the device and demonstrated immediate loss of consciousness, subjectively assessed by behavioural signs and no recovery. Post mortem examination of the heads was undertaken confirming massive traumatic damage to the cerebrum with associated haemorrhage and bone plate shards forced down to the level of the corpus callosum in the majority of cases. A further trial of 106 piglets demonstrated that under commercial production conditions it took less than seven seconds to select, place and euthanase a piglet using the device. One hundred per cent of animals in the study were immediately killed. Given this complete kill rate and the sample size of the study, a statistical 95% confidence interval provides a maximum percentage of animals that would not immediately be stunned/killed, by this mechanical non-penetrating captive bolt system, to be at most 1.2% and at least 0%. The results of this study, combined with the previous study

allow for the recommendation that the Bock Industries Zephyr EXL is suitable as a single application euthanasia device for piglets up to 10.9 Kg liveweight.

Keywords: Animal welfare, Captive Bolt, Euthanasia, Mechanical Stunning, Piglet, Zephyr EXL

Introduction

On-farm casualty killing or the killing of surplus animals is traditionally performed by manual blunt force trauma which is carried out by administering a blow to the head either with a hammer or similar heavy instrument or, by swinging the young animal against the floor or a wall (FAWC, 2017). Although this method is widely used, it is heavily dependent on the strength and skill of the stockperson and consequently the probability of achieving an immediate and humane kill in all cases is low. Furthermore, a lack of proper training and human error can lead to pain and distress to the animal. It is also a method of killing that is aesthetically unpleasant for both the operator and any bystanders. Council Regulation (EC) 1099/2009 of 24 September 2009 on the protection of animals at the time of killing, Annex 1. limits the use of a manual percussive blow to the head to piglets ≤5 kg live weight, stating that this method shall not be used as a routine method but only where there are no other methods available for stunning and no more than seventy animals per operative, per day, may be killed by this method.

Earlier field studies using the lower powered Zephyr E (bolt energy = 20 J) employed a three-application method (two in rapid succession on the frontal bone followed by a third at the back of the skull behind one ear) (Casey-Trott 2013) or, a two-application method (Casey-Trott 2014) for the euthanasia of piglets. Following these studies, the manufacturer, Bock Industries PA developed the Zephyr EXL, which delivers more power (bolt energy = 27.7 J *cf* 20 J) to negate the requirement for repeat application of the device to the animal. A previous study examined the effectiveness of the higher-powered Zephyr EXL non-penetrating captive bolt system, for the euthanasia of new-born and weaned piglets up to 10.9 kg liveweight (Grist, *et al.*, 2017). This study conducted under laboratory conditions demonstrated that a single application positioned on the frontal-parietal bone abolished visual evoked potentials immediately in all the piglets.

The AVMA (2013) amongst others, encourages those using manual blunt force trauma as a euthanasia method to seek alternative techniques, for example they recommended that a mechanical percussive blow to the head can be used for piglets up to 3 weeks of age. As such, this non-penetrating captive bolt mechanical blunt force trauma (MBFT) device i.e. the Zephyr EXL, can be considered to comply with the US Humane Slaughter Act Section 1902 that requires that an animal is rendered insensible to pain by a single blow and Council Regulation (EC) 1099/2009 of 24 September 2009 on the protection of animals at the time of killing, Annex 1. Therefore, the use of mechanical non-penetrative captive guns to both stun and kill neonate piglets offers a more reproducibly humane method of casualty killing on-farm.

This second stage of the assessment of the Zephyr EXL involved a field trial that was conducted in two phases: Phase One assessed the dispatch of 207 piglets using the Zephyr EXL with a single application in the frontal-parietal area; Phase Two was the dispatch of 106 piglets at operational speed, the second phase being conducted once confidence of the outcome was gained from Phase One. The Phase Two trial was a practical, on-farm confidence assessment.

Materials and Methods

Animals and Procedures

The overall study was carried out with the approval of the University of Bristol's Ethical Review Committee.

Phase One: Field trial

Compromised piglets (n=207 average weight 1.86 kg ± 0.74) were collected and brought to the shooting point separate to the farrowing area in a ~15,000 sow commercial unit in Texas, USA. All the piglets were selected by experienced farm personnel as requiring euthanasia following the normal criteria operated in the commercial unit. Each piglet was individually restrained on a polypropylene swine restraint assembly (Bock Industries, Figure 1) having its legs placed through the holes in the assembly by an experienced researcher (S.Wotton) whilst being loosely held with one hand and the device applied once in the parietal position (Figure 2) with a Zephyr EXL (Bock Industries, PA, USA, Gun number 722) powered at 120 psi by a Hitachi EC510 air compressor. It has been reported (Grist et al., 2017) that it is important that, as well as the use of the correct application position, the head of the piglet must be held firmly against the restrainer surface.

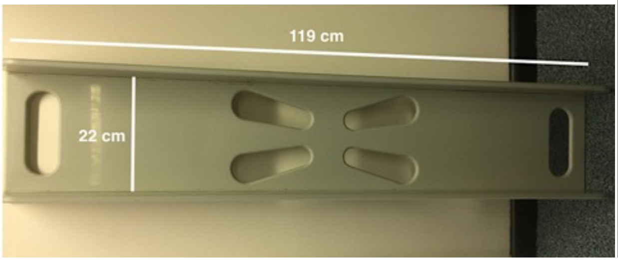

Figure 1. Polypropylene Bock Industries restrainer used in trials

Figure 2. Application position– body restrained with free hand

Following the application each piglet was examined by the researcher (S.Wotton) for behavioural signs of brain dysfunction including loss of rhythmic breathing, loss of palpebral and corneal reflex and non-responsiveness to nose prick with a hypodermic needle. The presence of a heartbeat was also assessed by the researcher (S.Wotton) by auscultation. Movement post-application was assessed subjectively based on the descriptors given in Table 1 whilst the animal was still in restraint. All measurements were continued for a minimum of 3 minutes post application and all findings were recorded by a second technician. Recovery of rhythmic breathing did not occur in these animals during the assessment period (3 minutes), which would indicate severe irrecoverable damage to the brain stem, the control centre for breathing (Hewitt, 2000).

Score	Descriptor	Description
0	No activity	Very little convulsive movement.
1	Mild activity	Some physical movement of limbs (paddling) that is manageable.
2	Moderate activity	Considerable physical movement of the limbs.
3	Severe	Severe physical movement (paddling of limbs)

Table 1. Subjective scoring system used to assess post-stun/kill movement based on level of post-application spinal reflex activity, ranging from 0 (no clonic activity post-stun) to 3 (severe uncontrolled physical movement (paddling))

Once death was verified (no brain stem reflexes and no breathing for >3minutes) the piglet was numbered on the ear with an indelible marker, removed from restraint and weighed to the nearest 0.25 kg on a 44lb stainless steel dial scale (Item No. 755105 Gandermountain, USA). The head was removed, placed in a resealable zipperlock bag with the corresponding piglet number repeated on the outside. The bagged heads were placed in a freezer for 24 hours for subsequent sectioning and examination. Freezing being undertaken to facilitate sectioning on the medial plane without disruption of macroscopic lesions during cutting.

Post mortem examination of the head

Each head was removed from the bag once the number had been noted, the ear number was checked to ensure correlation. The head was split on the sagittal plane using an electric band saw (Craftsman, USA) and both sides were photographed on the medial plane with a Pentax WG-1 digital camera (Pentax Ricoh Imaging

Company, Ltd, Japan) and post mortem findings recorded. Two researchers agreed on the macroscopic brain lesions, blind to the weight ranges and piglet numbers, utilising a subjective scale adapted from Sharp et al (2014) where 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The areas examined for macroscopic damage were the frontal, parietal and occipital cerebrum including the structure of the lateral ventricle as detailed in Figure 3.

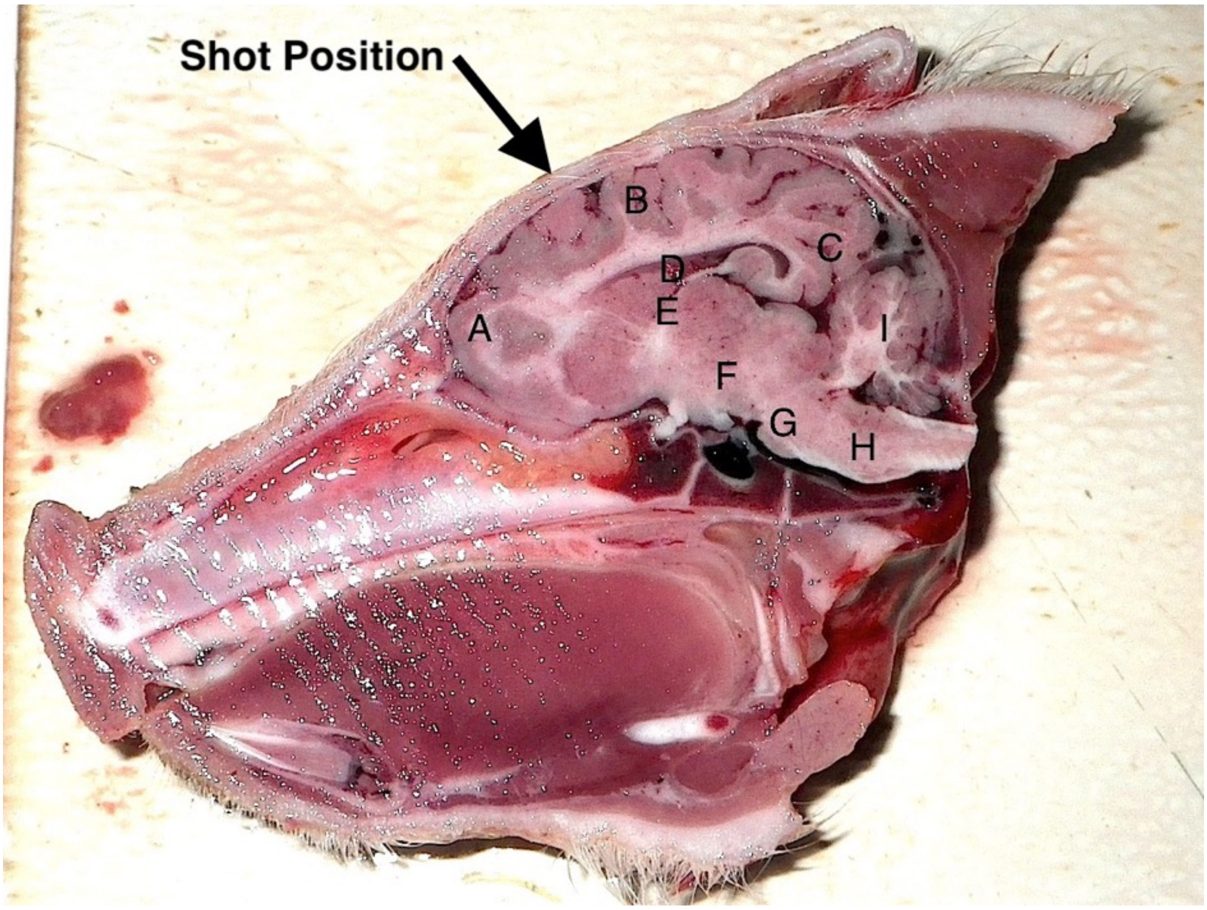

Figure 3. Sagittal section of a piglet head (intact found dead) illustrating the areas examined for macroscopic damage. A-Frontal cerebrum, B-Parietal cerebrum, C-Occipital cerebrum, D=Lateral ventricle. These areas were scored on the basis of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 =severe deformation of the area. Areas E-I (Thalamus, midbrain, pons, medulla and cerebellum respectively) were assessed for presence or absence of haemorrhage.

Phase Two: Practical on-farm application trial – assessment of the speed of operation

Piglets (n = 106), selected by the farm staff on the same farm as Phase One, as requiring euthanasia following their normal selection protocols, were delivered to the study area, separate to the farrowing area, in wheeled containers. Each piglet, of similar age and weight to phase 1, selected at random, within 10 groups of between 10 and 13 animals (table 2), was removed from the container by the researcher (S.Wotton), placed on the restraint device and the device applied once by the researcher in the frontal-parietal position before being placed in a second container. The time taken to stun/kill each batch of piglets from placing each piglet, applying the method and removing the piglet, was recorded and the effectiveness of the operation on the piglets in the second container was assessed by a second experienced researcher using the behavioural indices of brain dysfunction described above, death being verified by no rhythmic breathing movements for ≥3 minutes.

Statistical Analysis

Statistically, 100% efficiency can never be absolutely proven, there will always be some small margin for error, however large the study. However, a sample size of 200 was in practice a reasonable figure to demonstrate the degree of efficacy of the method, this initial figure was increased to > 300 (n=313) by the addition of data from Phase 2 of the trial. A sample of this size would give a 95% confidence interval, should 100% of 313 animals be effectively stun/killed, that the very maximum possible percentage of animals not immediately stunned/killed in normal use, and therefore requiring a second application of the device would be, at most, no more than 1.2% (Wilson's Method in Altman et al 2000). In addition to presenting the confidence intervals for single sample estimates the correlations between relevant variables were assessed using Spearman's Rho (r_s). The postmortem macroscopic brain lesion results were also tested for an overall linear correlation between individual piglet weight and the score for each of the four areas using a two tailed Spearman's rank correlation test (Spearman's Rho (r_s)). All statistical analyses were carried out using IBM SPSS Statistics (v23).

Results

Phase One: Field Trial

Piglet weight.

The distribution of piglet dead weights is shown in Figure 4, with a range from 0.25 to 3.75 kg (average weight 1.86 kg ± 0.74). The ages of the piglets ranged from newborn to 15 days with an average of 4.43 days.

Behavioural indices of brain death

One hundred percent of the piglets demonstrated immediate cessation of brain stem reflexes (n = 207, 95% CI for percentage immediately killed = 0% to 1.8% (Wilson's method)), including rhythmic breathing, palpebral reflex, corneal reflex and pain stimuli response. One piglet received a second application of the device in the poll position as a precaution as it demonstrated some agonal gasping movements at 10 minutes post application, however the piglet demonstrated no other brain stem reflexes. The piglet stopped agonal breathing immediately following the second application.

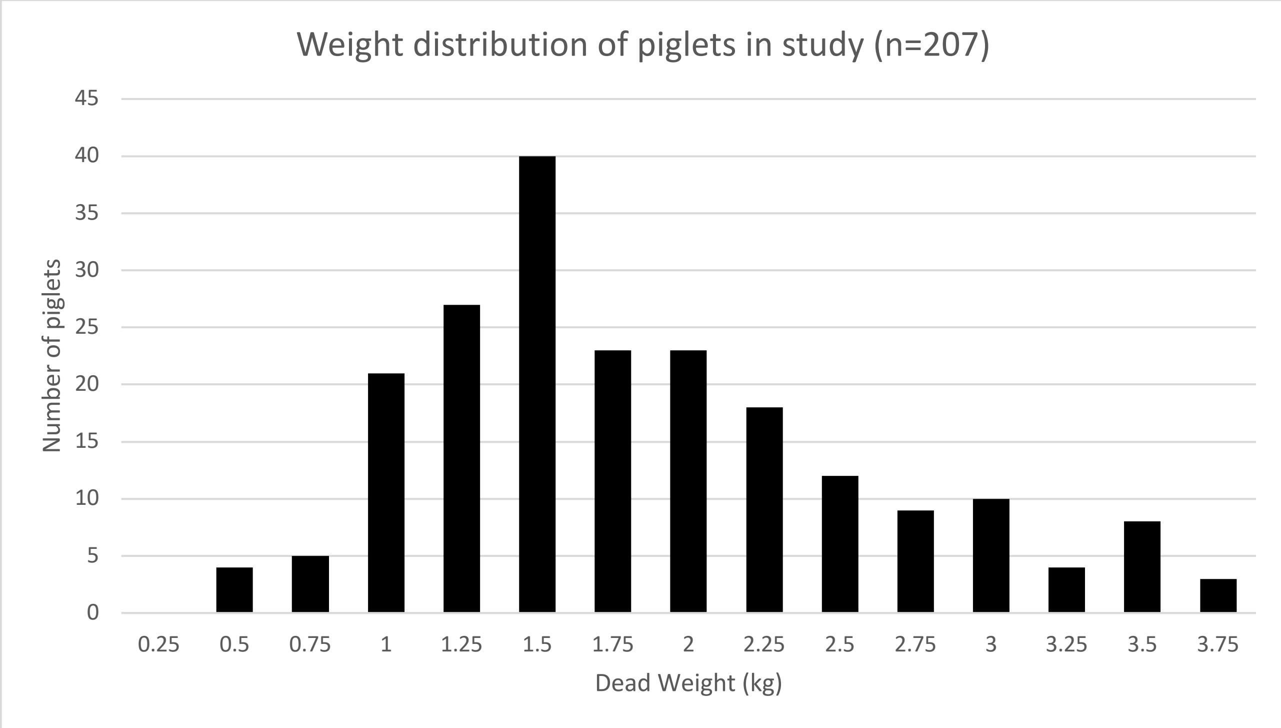

Figure 4 Weight range distribution of piglets in trial (n=207, average weight 1.86 kg ± 0.74)

Animal movement

Correlation analysis (Spearman's rho) demonstrated a significant correlation between (a) movement scores and weight (r_s = 0.611, n = 207, P ≤ 0.001) demonstrating that higher movement scores were associated with heavier piglets, (b) weight and end of movement time (r_s = -0.364, n = 198, P ≤ 0.001) demonstrating that the larger weight piglets cease movements earlier than lighter piglets and (c) weight/age and end of movement time (r_s = -0.405, n = 207, P ≤ 0.001) demonstrating that higher movements are associated with younger piglets.

Agonal gasping

Thirty-four (16.43%) of the piglets displayed intermittent agonal gasping movements post application. None of these animals demonstrated any brain stem or cranial reflexes and all had a 'normal' heartbeat immediately post stun. There was no significant correlation between the onset of agonal breathing and age (r_s = -0.065, n = 34, P = 0.716 (2-tailed)) or weight (r_s = 0.143, n = 34, P = 0.4211 (2-tailed)).

Haematoma and bleeding

Nasal haemorrhages were recorded with 158 piglets (76.33%, 95% CI = 70.1 to 81.6%) and laceration to one side of the impact point was recorded with 31 piglets (14.98%, 95% CI = 10.8 to 20.5%), the piglets with the latter condition were the only experimental animals that did not develop a large haematoma over the impact point (Figure 5)

Figure 5. Characteristic haematoma associated with impact point of device

Post mortem

The main post mortem finding was a depressed fracture of the skull with a concurrent subdural haematoma with parts of the occipital and parietal lobes prolapsed through the fracture. Fracture of the parietal plate was a common finding with bone shards forced into the medial dorsal cerebrum resulting in crushing of the frontal lobe of the cerebrum. The structure of the *corpus callosum* was generally severely compromised and parenchymal haemorrhages were evident within the thalamus, frontal parietal and occipital lobes of the cerebrum. Haemorrhages were encountered throughout the cranial cavity (Figure 6)

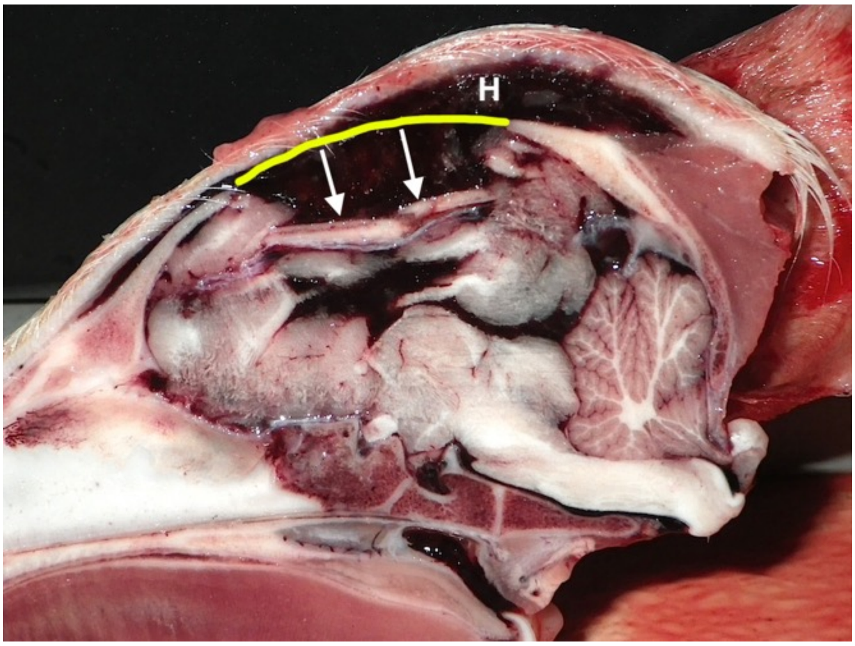

Figure 6. Example of post application trauma, medial sagittal section Piglet 17. Haematoma (H) evident, yellow line denotes approximate curve of cranial cavity in the live animal, the arrows demonstrating the displacement of bone shards into the brain.

Macroscopic lesion scoring

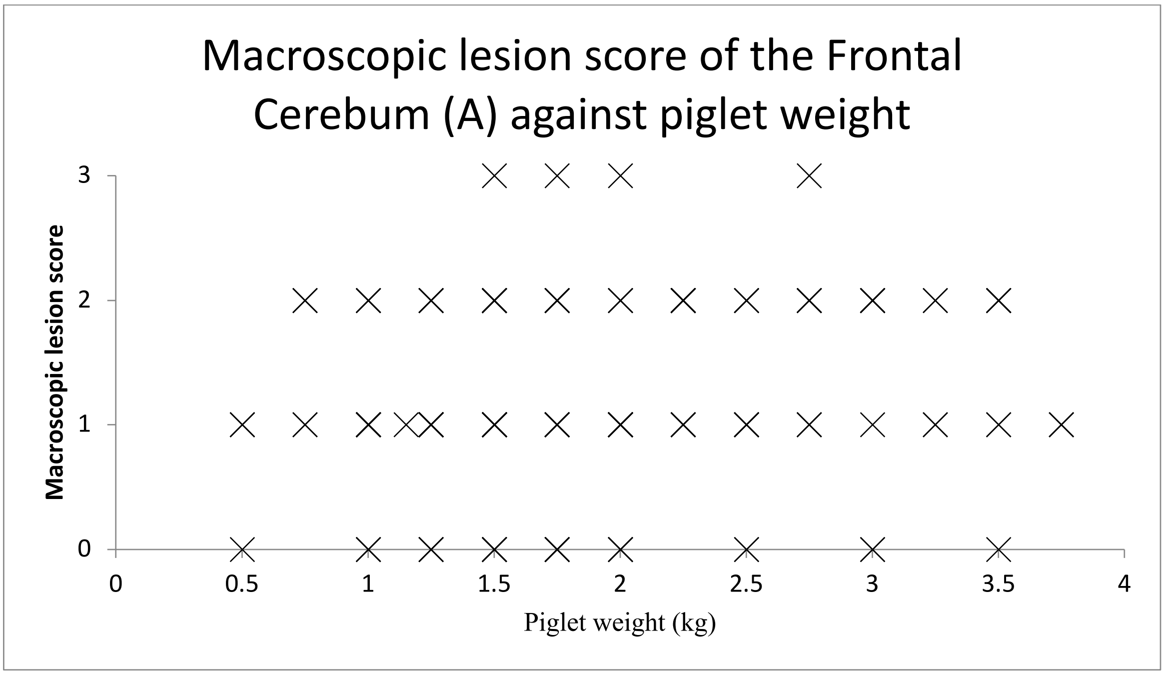

Figure 7: Graph of macroscopic lesion score of the frontal cerebrum against piglet weight. Subjective brain macroscopic lesion scores (0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 =severe deformation of the area) for the frontal cerebrum gave a positive correlation with piglet weight that was very statistically significant (Spearman's rho = 0.185, n = 207, p = 0.008).

Macroscopic lesion scores for the parietal cerebrum showed no correlation (Spearman's rho = 0.082, n = 6206, p = 0.243) with piglet weight and neither did occipital cerebrum lesion scores (Spearman's rho = 0.006, n = 206, p = 0.0.934) or lateral ventricle lesion scores (Spearman's rho = -0.054, n = 206, p = 0.437). Figure 7 demonstrates the positive correlation between the macroscopic brain lesion score of the fontal cerebrum and piglet weight.

Phase Two: Practical on-farm application trial

All the piglets showed immediate loss of sensibility and no positive brain stem reflexes or a response to a nose prick with a hypodermic needle (n = 106, 95% CI for percentage immediately killed = 0% to 3.5%). The mean time taken to pick up a piglet, place it in the restrainer, shoot and remove it from the restrainer was 6.45 seconds (Table 2).

Number of piglets in group	Time taken per group (secs)	Average time per piglet (secs)
13	108	8.31
13	108	9.31
10	61	6.10
10	55	5.50
10	56	5.60
10	67	6.70
10	57	5.70
10	64	6.40
10	64	6.40
10	55	5.50
n = 106	695	Mean 6.45 s / piglet

Table 2. Time taken to perform euthanasia on groups of piglets using the Zephyr EXL non-penetrating captive bolt.

Following successful completion of experimental Phases 1 and 2, the study team undertook on-farm training of farm staff to explain the correct use of the instrument and the scientific basis of NPCB operation, and most importantly the physical and physiological signs that should be expected in a properly stun/killed piglet.

Discussion

The Zephyr EXL powered at 120 psi provided for immediate loss of consciousness and brain death in all 207 piglets in a commercial setting with a single application of the device to the frontal-parietal position and with the head resting against a hard surface (Bock Industries restrainer –Figure 1). This field trial validates the findings of the laboratory assessment of the effectiveness of the Zephyr EXL in which visual evoked potentials were immediately lost in all piglets with the device applied in the same manner (Grist et al, 2017). The design and reporting of this and the previous study (Grist, et al., 2017) was guided by the published EFSA guide (EFSA, 2013) in order to ensure that the information can be used by EFSA to assess whether the use of a non-penetrating captive bolt can be used as a killing method for neonate piglets. Combining the figures from the two on-farm trails (N=313) the upper confidence limit (Wilson's method) is reduced, so that based on this relatively small sized trial, the very maximum percentage of animals not immediately stunned/killed and requiring a second application would be no more than 1.2% when used commercially.

As with the previous laboratory assessment a percentage of animals demonstrated agonal gasping (not rhythmic breathing) post application (16.43% in the field trial *cf* 15% in the laboratory). This was previously theorised to be indicative of residual partial isolated spinal neuronal activity due to changes in the plasma partial pressure of CO_2 (PCO_2) levels and pH in a brain-dead animal with a 'normal' post stun/kill heartbeat (Wijdicks 1995). St John (2009) describes the activation of latent pacemaker mechanisms following hypoxia, ishaemia or removal of the influence of the pons and rostral medulla, Terlouw (2016) stated that gasping precedes death and reflects dysfunction of brain areas including centers within the pons and medulla.

The macroscopic brain lesion and movement score results differed from the laboratory experiment reported by Grist, et al. (2017) which found a reduction in macroscopic brain lesions with increased piglet weight. It is presumed that this is due to various factors including the smaller weight range of the animals in this field trial (0.5 to 3.75 kg *cf* 1.0 to 10.9 kg), and the fact that the field trial piglets were euthanased for ill health and under performance (with possible lack of skull development) as opposed to the laboratory trials which purposely used healthy animals to give a conservative assessment of the effectiveness of the Bock Industries Zephyr EXL on piglets of a given weight range. There was no correlation found between the macroscopic brain lesion scores and either movement score or time to loss of movement.

During the field trial the farm workers expressed some concern over the post application movements and this concern correlated with the findings of previous studies (Matthis 2004, Gemus-Benjamin 2015). This concern abated once the physical characteristics of post stun/kill spinal reflexes were explained during a training seminar where the absence of brain stem reflexes was practically demonstrated by the researchers. Movement following brain disruption has long been hypothesized as being due to spinal rhythm generators (Guertin, 2009: Pearson et al., 1998) and does not relate to consciousness; this has been demonstrated by Terlouw et al., (2015) who recorded movement in stunned cattle after isolation of the spinal cord by post stun severance between the foramen magnum and the first cervical vertebra. The level of post brain death movement, encountered in the piglets, corresponds to levels found in human patients that in various studies ranged from 10% spinal automatisms (Spittler 2000) to as high as 39% (Saposnik 2000).

Conclusions

This field trial, in conjunction with laboratory trials (Grist et al., 2017) lead to the conclusion that the Bock Industries Zephyr EXL is effective in producing a stun/kill in neonate piglets (up to 10.9Kg) with a single apllication placed on the top of the head at 120 psi with the head resting on a solid surface; as such, it represents a viable alternative to manual blunt force trauma as a method of piglet dispatch.

Animal Welfare Implications

This mechanical blunt force trauma device (Bock Industries Zephyr EXL) provides an immediate, single application, stun-kill of neonate piglets that may require dispatch for any purpose including ill health, disease control, mercy or production efficiencies. The device also has a low deviation (<1%) of velocity with each firing (Lines, personal communication, 2015). It is important that the behavioural signs of a proper stun/kill application are explained to operators and that clonic activity will occur but is a sign of a successful application.

Acknowledgements

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Chapter Three

On farm euthanasia of neonate animals – Evaluation of the Accles and Shelvoke Small Animal Non-penetrating Captive Bolt Device

3.1. Candidate Contribution for Papers Three, Four and Five

Andrew Grist was involved in the initial discussions into this research concept and contributed to the experimental design of this project in conjunction with the other authors.

Andrew Grist assisted in on-farm euthanasia and behavioural assessment of brain death and movement scoring and correlation of heads for later postmortem examination. Andrew Grist performed macroscopic postmortem examination of the 202 piglets, 200 kids and 248 lamb heads, assessing macroscopic brain lesion scores and developed the Skull plate displacement scoring system (Figure 7 in paper three). As a key part of the research was assessing the required shot position Andrew Grist developed a targeting scoring system which was applied during the postmortem examination (Figures 3 and 4 in paper Four and Figures 2 and 3 in Paper Five) and correlated with the on-farm euthanasia scoring of behavioural indicators of brain death, post-shot movement scoring system and agonal breathing. Andrew Grist assessed all heads for fracture patterns and recorded all on-farm and postmortem data in an Excel programme he created. Andrew Grist also assisted with the statistical analysis of results and, in conjunction with the principal investigator, decided what to include in the published paper.

Andrew Grist wrote the papers and created all the figures and tables in the journal format, which was then sent to team members for comment. The Journal used asked for paper submission in their Special Edition covering “Humane Killing and Euthanasia of Animals on Farms" based on the previous two papers in Chapter One.

Andrew Grist dealt with reviewer comments to the satisfaction of the journal prior to publication. Andrew Grist provided proof copies to the journal within the timeframes they required.

Andrew Grist recognised and researched neopallial cysts (proencephaly) encountered during the postmortem examination in papers Three and Four.
Andrew Grist conducted further research and review of the mechanisms of agonal breathing for the papers.

3.2 PAPER THREE

The use of a non-penetrating captive bolt for the humane euthanasia of neonate piglets. Andrew Grist, Jeff A. Lines, Toby G. Knowles, Charles W. Mason and Stephen B. Wotton

Animals Special Issue on Euthanasia, Animals 2018, 8, 48; doi:10.3390/ani8040048

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The use of a non-penetrating captive bolt for the humane euthanasia of neonate piglets

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Simple Summary: The humane destruction of newborn piglets (neonates) when required is an issue faced by farmers and producers. The application of blunt force trauma, either through swinging the animal against a wall, or hitting it with a weighted object, is a stressful procedure for the stock person and has implications for the animal in terms of welfare, instantaneous effect and reproducibility. The United Kingdom government funded this project to find a single application method that could be used on farm, that would produce an immediate kill with these animals. This project demonstrates that the use of a mechanical captive bolt device, that does not enter the head, delivers sufficient energy when applied to the head of a piglet to immediately destroy the brain leading to the death of the animal. This method will improve animal welfare on farms, as well as providing producers with a device that they can be

confident will kill the animal without pain, as the brain is destroyed before the animal can perceive a pain nerve impulse.

Abstract: The most common method for the on-farm euthanasia of neonate piglets is reported to be manual blunt force trauma. This paper presents the results of research to evaluate a mechanical non-penetrating captive bolt (the Accles and Shelvoke CASH small animal tool) to produce an immediate stun/kill with neonate piglets. One hundred and forty-seven piglets (average dead weight =1.20 kg ±0.58 (SD), mean age = 5.8 days (median = 3)) were euthanized with the device and demonstrated immediate loss of consciousness, subjectively assessed by behavioural signs and no recovery. The result that 147 out of 147 animals were effectively stun/killed gives a 95% confidence interval for the true percentage of animals that would be effectively stun/killed of 97.5 to 100% with the use of the CASH small animal tool under the conditions of the current study. This research concludes that the CASH small animal tool, using a 1 grain brown coded cartridge, is suitable for producing a stun/kill in neonate piglets when applied in a frontal/parietal position.

Keywords: Animal welfare; Euthanasia; Livestock; Mechanical killing; On-farm killing; Neonate piglets

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1. Introduction

Occasionally stockmen will be faced with the problem of having to dispatch, or euthanase, young piglets for various reasons including illnesses that are beyond treatment, birth deformations or production efficiencies. Usually, in the case of illness the choices that are available to the producer are either leaving the neonates with their mothers in the hope that they may recover, or casualty slaughter. Euthanasia or slaughter of surplus young animals on-farm is usually carried out by administering a blow to the head, which is generally performed with a percussive blow or by swinging the young animal against the floor or a wall. Although widely used as a means of casualty slaughter the effectiveness of this method is heavily dependent on the strength and skill of the operator and consequently the probability of consistently achieving an immediate kill is low. Furthermore, lack of proper training and human error can lead to pain and distress to the animal. It is also a method of killing that is aesthetically unpleasant for both the operator and any bystanders [1,2,3]. As the terms 'dispatch', 'euthanasia', 'casualty or surplus slaughter' and 'culling' are all commonly used to describe the termination of life, we will use the term euthanasia in this paper to encompass them all.

The Humane Slaughter Association carried out a survey in 1996 [4] to look at the euthanasia methods used for young lambs and piglets. The results showed that the majority of young, sick lambs are left to die, whilst a manual blow to the head was the normal method applied to casualty piglets. The majority of respondents were not satisfied with their current method of euthanasia and all of them expressed an interest in an alternative method. Unfortunately, currently there is no approved available alternative method for euthanizing young livestock in the United Kingdom.

There are many considerations for evaluating the effectiveness and acceptability of on-farm euthanasia techniques. Over the past several years, animal welfare experts, industry organizations, animal welfare groups and governmental agencies have detailed their primary concerns and recommendations in various publications [5-10].

While differing slightly, the basic criteria remain fairly constant; the ability to induce loss of consciousness and death without causing pain or distress, the time required for loss of consciousness and death, compatibility with intended animal use and purpose, operator safety, reliability, cost, practicality, aesthetics and emotional impacts, environmental impacts, and legal requirements.

A previous DEFRA project (MH0116) examined the reliability and output of several mechanical devices, one of which, the Accles and Shelvoke CASH Small Animal Tool (CPK200, Birmingham, UK) was found to be reliable, to produce a kinetic energy that would, theoretically, stun/kill neonates and which produced a consistent output. The use of an alternative tool, the Zephyr EXL for the euthanasia of piglets is reported elsewhere [11,12]. This paper examines the use of the Accles and Shelvoke Cash Small Animal Tool in practical use for the humane euthanasia of neonate piglets.

This paper reports the methods and findings of DEFRA project MH0150, "a Study to investigate a non-penetrating percussive blow to the head as a humane killing method for piglets up to 5 kg", a study approved by the University of Bristol's Ethical Committee and carried out under a United Kingdom Home Office Licence.

1.1. Description of CASH small animal tool

The CASH Small animal tool, formally designated CPK200, is a non-penetrating captive bolt (Figure 1 and 2) powered by a brown colour-coded 0.22" calibre rimfire blank cartridge containing 1 grain (65 mg) single base propellant (nitrocellulose) as its power source. The gas expansion chamber of the breech has a length of 20mm. The bolt can travel further than 20 mm by disengaging from the expansion chamber. Although the total available travel for the bolt is 110 mm, it is constrained by buffers, or recuperating sleeves, that are slightly compressed even when the bolt is at rest and become progressively more compressed as the bolt extends. At rest, the bolt head is retracted 6 -10 mm from the point at which it contacts the target. When the recuperating sleeves are in good condition the total travel of the bolt ranges from 25 to 35 mm. In a pure ballistic situation, the energy of the explosive cartridge is fully converted into kinetic energy before impact so that the sole source of energy at impact is the kinetic energy of the projectile. The CASH small animal tool cannot therefore be considered a ballistic device since the bolt may make contact with the target after a travel of only 5 or 10 mm, while it remains engaged with the expansion chamber. It is therefore subject to the force of the expanding gasses for a further 10-15mm of travel. In the absence of an impact target, the bolt may be expected to accelerate over a distance of up to 20mm and thereafter decelerate. Without a detailed knowledge of the velocity profile of the bolt as it impacts the target and the dynamic characteristics of the recuperating sleeves, it not possible to identify with precision the proportion of energy absorbed by the recuperating sleeves and that delivered to the target. However, the maximum velocity achieved by the bolt, in the absence of an impact target is likely to be a representative measure of the energy available at impact. The average kinetic energy produced on impact by this device is 47 Joules when using a 1 grain cartridge and 107 Joules when using a 1.25 grain cartridge. Previous work [11] demonstrated that a non-penetrating device producing a kinetic energy of 27 Joules was sufficient to stun/kill neonate piglets using loss of visual evoked potentials and loss of brain stem reflexes as a determinant of brain death.

Figure 1. Accles and Shelvoke 'Cash' Small Animal Tool. A 0.22" caliber blank cartridge powered non-penetrating captive bolt device.

Figure 2. Bolt components of the non-penetrating captive bolt (adapted from Accles and Shelvoke)

2. Materials and Methods

Animals and Procedures

The piglets (n=202), average dead weight = 1.222 kg (±0.665 (SD), , mean age = 5.7 days (median = 3)), used in this objective were commercial hybrid large white/landrace crosses bred by DanBreds International and were animals destined to be euthanized according to the farm's standard protocols either due to disease, malformation or production efficiency. All of the animals used in this project were either animals destined to be killed on the grounds of casualty slaughter or routine farm management during eighteen visits to the commercial sow unit. The participating producers were instructed that animals that were suffering any pain and distress must not be held back and kept alive for this project but must be euthanased as soon as possible. Fifty-five piglets were euthanized with the device powered by a 1.25 grain cartridge. However, the cartridge strength chosen (pink 1.25-grain) resulted in damage to the piglets and excessive wear to the gun, in particular damage to the recouperator sleeves (buffers). Permission was obtained from the Home Office and Defra to lower the cartridge strength from 1.25-grain to 1-grain, following preliminary tests on cadavers, which reduced the average energy developed from 107 Joules to 47 Joules. The 1 grain powerload was used on the subsequent 147 piglets.

Device application

Piglets to be euthanized with the CASH small animal tool were placed in a sailcloth hammock attached to a tubular metal X-frame (Figure 3). This allowed the legs of the piglet to hang down without touching the floor and provided restraint for application of the device (Figure 4) and enabled a close evaluation of brain stem reflexes and piglet movement post-shot. The device was applied once in the frontal-parietal position of the piglet (Figure 5) by the researcher (SW) whilst gently restraining the animal with the free hand and assessed for behavioural signs of brain death. Previous research has shown that the following parameters meet the criteria for assessing the effectiveness of the application, i.e. clinical signs characterising a dysfunction affecting i) the cerebral hemispheres on a large scale, ii) the reticular formation or iii) the ascending reticular activating system or the median thalamus bilaterally [13]:

1. The absence of rhythmic breathing, which is controlled by structures within the medulla oblongata and innervated by the reticular activating system [13].
2. The absence of a positive corneal reflex, a reflex with a neural pathway that passes adjacent to, and partially through, the reticular formation. [13].
3. The absence of a positive palpebral reflex, which is a brainstem reflex.
4. The absence of response to painful stimuli (needle prick to the nose), a cortical arc reflex [13].

Any animal that showed signs of recovery, or rhythmic breathing, within the 3-minute evaluation time [14] or, that persisted beyond the 3-minute evaluation time, was killed immediately using an injected overdose of pentobarbital sodium (1ml 200mg/ml injection into the heart), (Euthatal, Merial, UK GTIN:03661103015550).

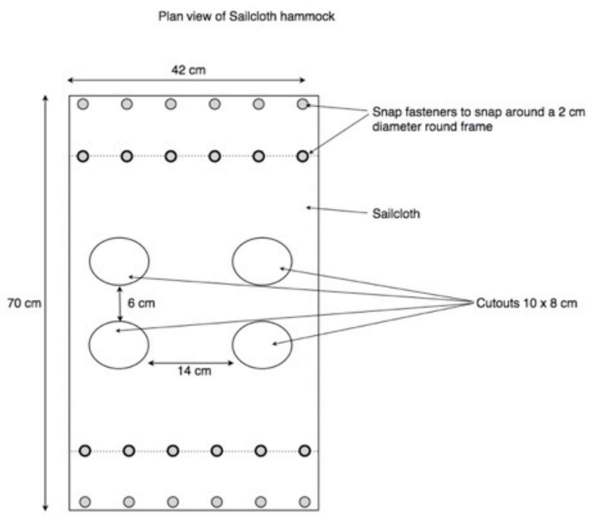


Figure 3. Sailcloth Hammock Design

Figure 4. Sailcloth Hammock in use (Cadaver used to demonstrate restraint).

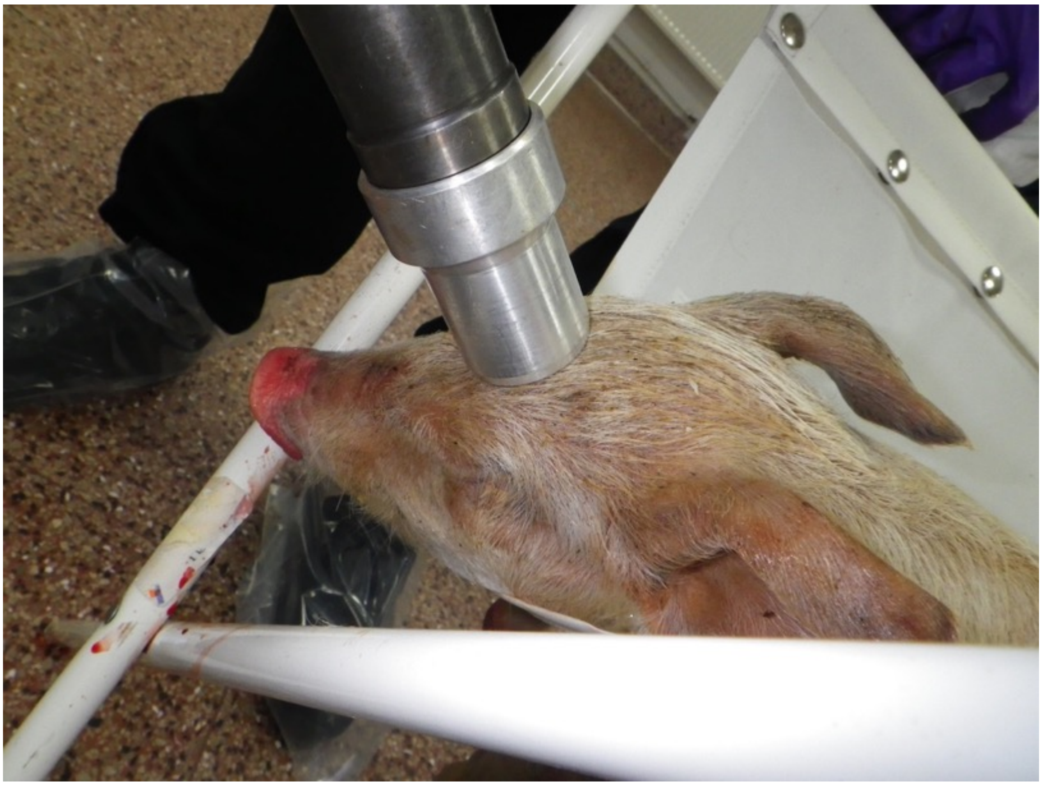


Figure 5. Shooting position for piglets on the midline on the frontal/parietal bone

Following the shot each piglet was examined by the researcher for behavioural signs of brain dysfunction. The presence of a heartbeat was also assessed by the researcher by auscultation, although this is not considered an indicator of death or life. Movement post application (clonic activity, leg paddling) was assessed subjectively according to the descriptors in Table 1, time to end of movement was recorded from the application to the end of activity. All brain function measurements were continued for 3 minutes post shot [14] and all findings were recorded by a technician.

Table 1. Subjective scoring system used to assess post-stun/kill movement based on the level of spinal reflex activity, ranging from 0 (no clonic activity post-stun) to 3 (Severe uncontrolled physical movement)

Score	Descriptor	Description of intensity
0	No activity	Very little clonic activity.
1	Mild activity	Some mild uncontrolled physical movement of limbs.
2	Moderate activity	Considerable uncontrolled physical movement of the limbs.
3	Severe	Severe uncontrolled physical convulsive movement, paddling of legs

Post mortem examination of heads

Section 1 – *Post mortem* examination

All experimental animals were frozen after killing and subsequently thawed for post mortem examination. The intact heads of the piglets were photographed using a digital camera (PENTAX Optio WG-1 or PENTAX K-50 (Pentax Ricoh Imaging Company, Ltd, Japan)). The skin from the head was removed following a T incision cranial to the shoulders and extending forward to the nose. The impact site was photographed before removal of any haematoma and the periosteum to expose fracture lines extending from the impact site. Photographs were taken of the fracture patterns to allow for later comparison. The heads were placed in individually numbered bags and subsequently hard frozen to facilitate sectioning on the sagittal plane for photography of cranial and brain lesions to be undertaken.

Section 2 - Sagittal plane assessment

Each head was removed from the bag once the number had been noted; the ear number was checked to ensure correlation. The head was split on the sagittal plane using an electric band saw (Startrite Meat Master, UK) and both sides were photographed on the medial plane with a digital camera (PENTAX Optio WG-1 or PENTAX K-50) and post mortem findings recorded.

Two researchers assessed the macroscopic brain lesions separately, and blind to the weight and piglet number, utilising a subjective scale adapted from Sharp, et al., [15] and reported in Grist, et al., [12] where 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The researchers then agreed final figures. The areas examined for macroscopic damage were the frontal, parietal and occipital cerebrum including the structure of the lateral ventricle as detailed in Figure 6. The thalamus, midbrain, pons, medulla and cerebellum were assessed for presence or absence of haemorrhage. The percentage displacement of the cranial bone in relation to the surface was also assessed using a 0 to 100% scale that was expanded proportionately to each sagittal photograph, with 0% being the cranial surface and 100% located at the bone peak between the optic chiasma and mammillary body, such that a score of 50% would indicate that bone plates were evident half way between the normal cranial plate surface and the base of the brain (Figure 7).

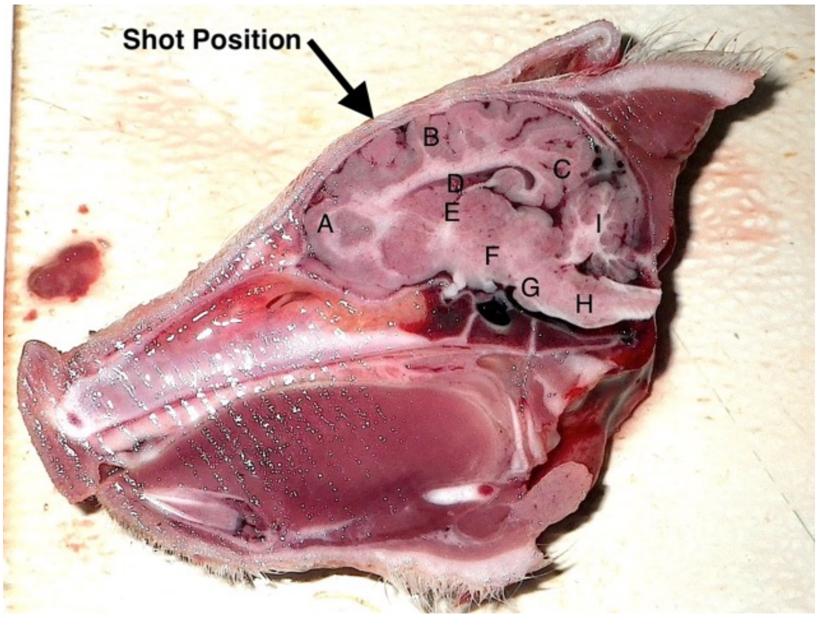


Figure 6. Sagittal section of an unshot piglet head (died on farm) illustrating shot position and the areas examined for macroscopic damage. A-Frontal cerebrum, B-Parietal cerebrum, C-Occipital cerebrum, D=Lateral ventricle. These were scored on the basis of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 =severe deformation of the area. Areas E-I (Thalamus, midbrain, pons, medulla and cerebellum respectively) were assessed for presence or absence of haemorrhage.

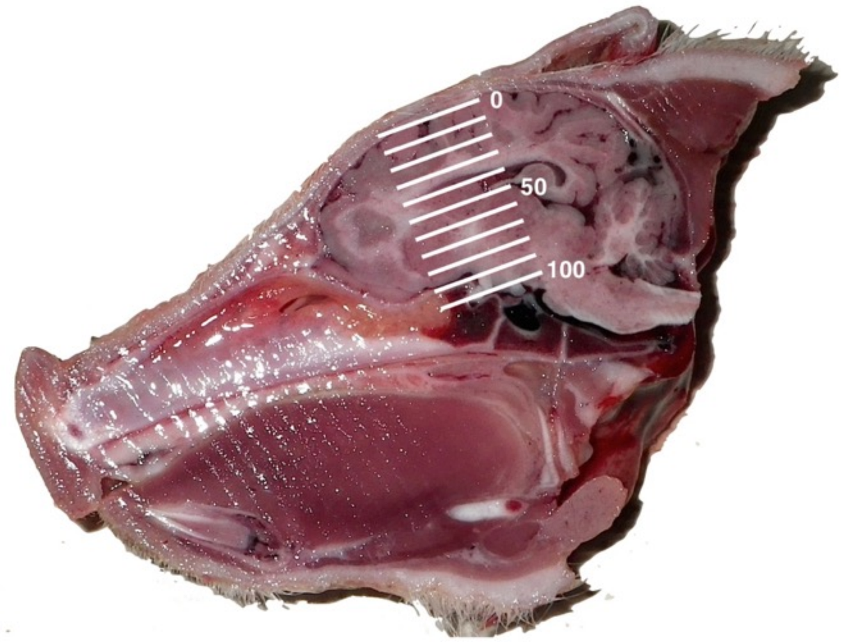


Figure 7: Skull plate displacement diagram. The level of skull plate displacement following the shot is expressed as a percentage, with 0 being no displacement and 100% being a case where the skull fragment was observed at the base of the cranial cavity. Each sagittal plane piglet photograph had the scale expanded proportionately for this assessment, with 0 located at the cranial surface and 100% located at the bone peak between the optic chiasma and mammillary body.

Statistical Analysis

Statistical advice suggests that 100% efficiency can never be absolutely proven, there will always be some small margin for error, however large the study. However, a target sample size of 200 was in practice a reasonable figure to demonstrate the degree of efficacy of the method. A sample of this size would give a 95% confidence interval, should 100% of 200 animals be effectively stun/killed, that the very maximum possible percentage of animals not immediately stunned/killed in normal use, and therefore requiring a second shot would be, at most, no more than 1.9% (Wilson's Method [16]). In addition to presenting the confidence intervals for single sample estimates the correlations between relevant variables were assessed using Spearman's Rho (r_s). The postmortem macroscopic brain lesion results were also tested for an overall linear correlation with individual piglet weight and the score for each of the four areas using Spearman's rank correlation test (Spearman's Rho (r_s)), in the IBM SPSS (v23) statistics package (SPSS Inc., Chicago, IL, USA). General linear models were also constructed to test for an effect of piglet dead weight, brain haemorrhage score, macroscopic brain damage score and nose/skin haemorrhaging/laceration on time to loss of movement, and also for their effect on movement score. The assumptions of normality of error and homogeneity of variance required for the models were tested and found to be satisfactory.

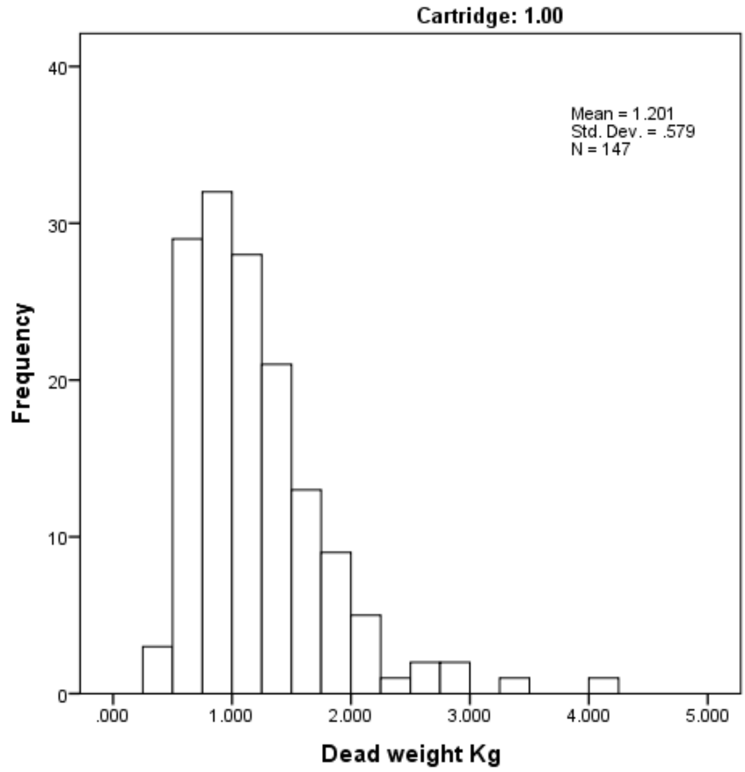
3. Results

The application of the CASH small animal tool resulted in an effective stun with every piglet and, in addition, every piglet was effectively killed by the procedure. Recovery of rhythmic breathing did not occur in these animals during the assessment period (3 minutes), which would indicate that severe, irrecoverable damage to the brain stem, the control centre for breathing, was achieved. The CASH small animal tool gun was initially used successfully on 55 piglets. A further 147 piglets were successfully stun/killed with the brown 1-grain cartridge, which resulted in reduced laceration to the skin over the impact area and less bleeding from the nostrils.

The result that 147 out of 147 animals were effectively stun/killed gives a 95% confidence interval for the true percentage of animals that would be effectively stun/killed of 97.5 to 100% with the use of the CASH small animal tool, with a 1-grain cartridge, under the conditions of the current study (Wilson's Method [16]). The confidence interval for the 55 successfully killed using the 1.25 grain cartridge is 93.5 to 100%.

Figure 8 shows the distribution of piglet dead weights (kg) across the range of casualty or surplus piglets that were presented for euthanasia by farm staff by the size of the cartridge used and figure 9 shows the frequency of the post-shot movement scores recorded. There was no significant difference in weight between the two groups ($t = -0.754$, $p = 0.452$), but a significant difference in movement score between the two groups ($U = 3090$, $p = 0.006$) with a mean score of 2.14 in the 1 grain cartridge group compared with 1.28 in the 1.25 grain group. The remaining variables were also tested for a difference between the two cartridge size groups. The results are shown in Table 2 below.

Figure 8 Distribution of piglet dead weights (kg) by cartridge used.



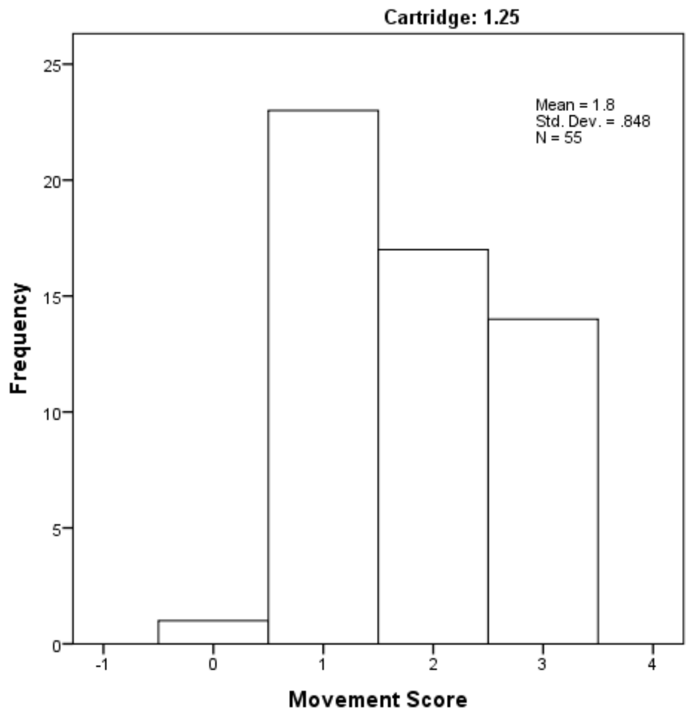


Figure 9 The distribution of piglet movement scores by cartridge size used, based on a subjective scoring where score 0 = Very little movement. Score 1= Some mild uncontrolled physical movement of limbs. Score 2= Considerable uncontrolled physical movement of the limbs, and score 3 = Gross uncontrolled physical movement.

Table 2. Results of the tests for differences in the remaining outcome variables between the two cartridge sizes. Showing the U statistic, significance and mean (se) within each group.

	U	Exact p	1-grain		1.25-grain	
			Mean	se	Mean	se
Time to loss of movement (s)	3760	0.446	101.88	4.49	86.95	4.21
Total Haemorrhage Score	2522.5	0.014	4.63	0.57	4.32	0.13
Total Damage Score	1543.5	0.000	7.22	0.14	8.68	0.26
Plate or Shard %	1215	0.000	15.2	0.97	27.44	1.78
Presence of nose bleed	3370.5	0.009	85.70%	2.30%	7.80%	6.50%

The shard plate displacement score correlated highly with the total brain damage score (R = 0.503, P<0.001) therefore in the following general linear model (GLM) analysis either one or the other was fitted however, we include estimates for both in the tables of parameter estimates. The estimates for the remaining parameters are from the model when it included total score. This presentation makes no substantive difference to the interpretation of the results. The effect of cartridge size group was also tested within the models, as a main effect with the other variables present and with all possible 2-way interactions. All terms failed to reach significance in both the time to loss of movement model (all p > 0.40) and in the movement score model (all p > 0.410). This cartridge group was dropped from both models.

3.1 Factors related to 'time to loss of movement

The parameter estimates from the GLM analysis of 'time to loss of movement' are shown in Table 3. This shows that there was no significant linear effect of dead weight, 'total brain haemorrhaging score', 'total brain damage score' or 'shard plate displacement score'. There was a significant effect of the presence of nose/skin haemorrhaging/laceration on 'time to loss of movement. On average, when these were present there was an associated decrease in 'time to loss of movement' of 36.86 (SE = 9.906) seconds. The mean time to loss of movement for piglets without haemorrhaging (nose bleed or skin laceration) was 124.03 s (S.E. = 10.216) and the mean time to loss of movement for piglets with haemorrhaging (nose bleed or skin laceration) was 92.82 s (S.E. = 3.375). Note these are actual means, not marginal means estimated from the analysis.

Table 3. Parameter estimates from the GLM testing for an effect of dead weight (kg), brain haemorrhage score, macroscopic brain damage score and nose/skin haemorrhaging/laceration on time to loss of movement.

Parameter	**B**	**S.E.**	**t**	**Sig.**
Intercept	134.031	27.562	4.863	0.000
Dead Weight (kg)	-1.935	5.628	-0.344	0.731
Total brain haemorrhage score	4.930	4.919	1.002	0.317
Total brain damage score	-3.270	2.023	-1.616	0.108
Nose/skin haemorrhage/laceration	-36.856	9.906	-3.721	0.000
Shard plate displacement score	-.412	.280	-1.473	.142

3.2 Factors related to 'movement score'

The parameter estimates from the GLM analysis of 'movement score' are shown in Table 4. This shows that there was no significant linear effect of total brain 'haemorrhaging score', 'total brain damage score' or, 'shard plate displacement score', although there may appear to have been a trend for a relationship with total brain damage score. There was a significant effect of nose/skin haemorrhage/laceration presence on 'movement score' and the relationship between these is shown in Table 5. There was also a significant effect of piglet dead weight on the movement score and this is shown in Figure 10. The analysis suggests that for every 1 kg increase in piglet dead weight there was an associated average 0.39 (S.E. = 0.083) increase in movement score (P<0.001).

Table 4. Parameter estimates from the GLM testing for an effect of dead weight (kg), brain haemorrhage score, macroscopic brain damage score and nose/skin haemorrhage/laceration on movement score.

Parameter	**B**	**S.E.**	**t**	**Sig.**
Intercept	1.491	0.408	3.651	0.000
Dead Weight (kg)	0.385	0.083	4.622	0.000
Nose/skin haemorrhage/laceration	0.488	0.147	3.325	0.001
Total brain haemorrhage score	0.024	0.073	0.324	0.746
Total brain damage score	-0.050	0.030	-1.656	0.099
Shard plate displacement Score	-0.003	0.004	-0.752	0.453

Table 5. The number of piglets that demonstrated a nose bleed or skin laceration for each movement score, where score 0 = Very little movement. Score 1= Some mild uncontrolled physical movement of limbs. Score 2= Considerable uncontrolled physical movement of the limbs and score 3 = Gross uncontrolled physical movement.

Nose bleed or Skin laceration	Movement Score			
	0	1	2	3
YES	1	26	77	60
NO	4	20	8	6

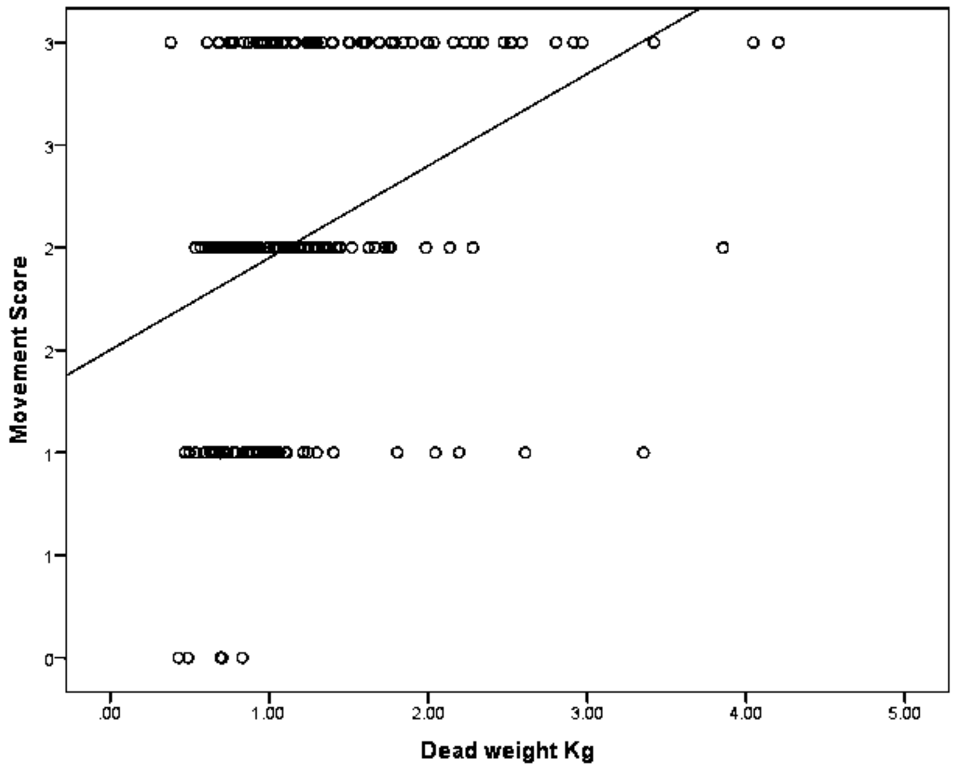


Figure 10. The relationship between piglet dead weight and movement score, where score 0 = Very little movement. Score 1= Some mild uncontrolled physical movement of limbs. Score 2= Considerable uncontrolled physical movement of the limbs and score 3 = Gross uncontrolled physical movement. N = 202.

3.3 Agonal Breathing

Eight of the 202 (4%) piglets developed agonal breathing, n=7, >3 minutes post-shot and n=1, ≤3 minutes post shot. All eight were in the 1-grain cartridge group. Post mortem findings suggest that the piglets that displayed agonal breathing suffered such severe brain damage that they could not have recovered from the percussive blow.

The mean duration of convulsions was 1 minute 43 seconds and depended largely on the physical state of the animal when it was dispatched. Some casualty piglets were in a very poor physical condition and these animals tended to move less post-shot.

3.4 Post mortem

All animals displayed a depressed fracture of the cranial plates and concurrent subdural haematoma corresponding to the impact footprint (Figure 11) of the convex head of the bolt (Figure 2). Fracture of the parietal plate was a common finding with bone shards forced into the medial dorsal cerebrum resulting in crushing of the parietal lobe of the cerebrum.

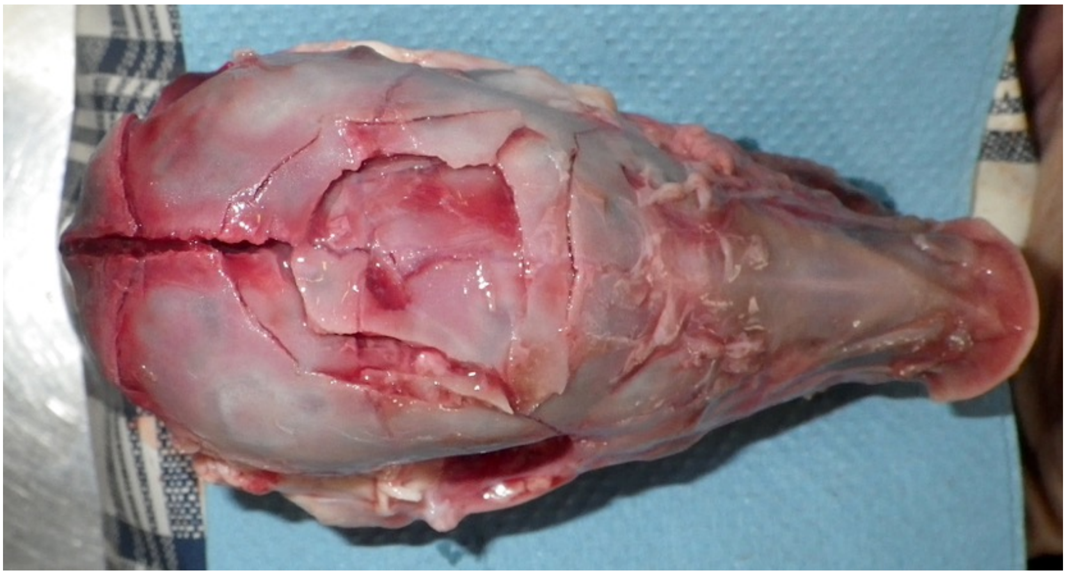
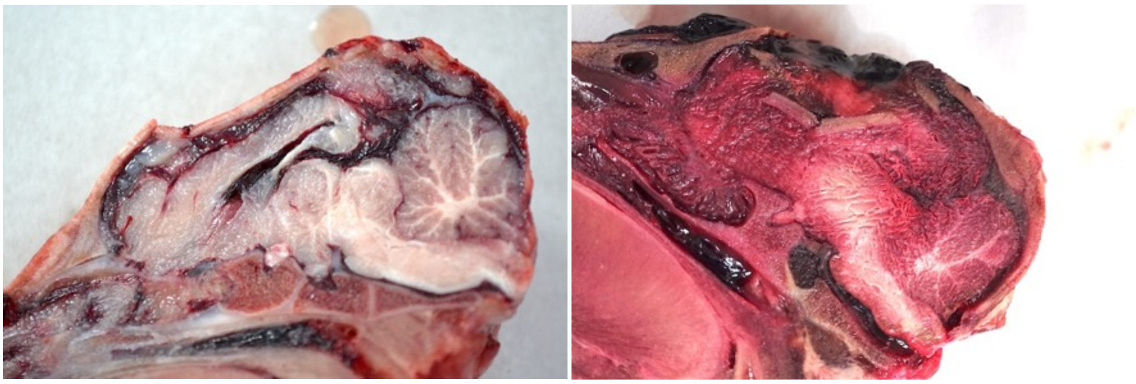


Figure 11. Fracture pattern at impact point. Skin, periosteum and haematoma removed

The structure of the *corpus callosum* was generally severely compromised and parenchymal ecchymosis evident within the thalamus, frontal parietal and occipital lobes of cerebrum and the cerebellum (Figure 6 & 12).



Piglet 110 (1.295kg) Piglet 185 (3.355kg)

Figure 12. Examples of post-shot trauma, medial sagittal section demonstrating bone fracture displacement and macroscopic brain damage (1 grain cartridge)

3.5 Haematoma and nasal haemorrhages

Table 6 shows the percentage and numbers of piglets that displayed nose bleed, broken skin and both, by cartridge size. A Chi-square test showed there to be a highly significant association between these conditions and the size of cartridge used.

	None	Nose bleed	Skin broken	Nb and Sb
1-grain	14.3% (21)	63.9% (94)	2.7% (4)	19.0% (28)
1.25-grain	30.9% (17)	20.0% (11)	41.8% (23)	7.3% (4)
Total	18.8% (38)	52.0% (105)	13.4% (27)	15.8% (32)

Table 6. The percentage of piglets with nose bleed and broken skin by cartridge size. Actual numbers are in brackets. There was a highly significant association between grain size and condition (Chi-square = 70.03, df = 3, exact $p < 0.001$). Analysis of the effect of haemorrhages from the nasal passages and skin lacerations is given in tables 4 and 5.

3.6 Cranial bone displacement

There was no significant correlation between piglet weight and the percentage bone displacement.

4. Discussion

This research demonstrated that the use of this percussive stun/kill device with a 1-grain cartridge resulted in an effective stun/kill with neonate piglets less than 28 days old (mean dead weight = 1.20 kg (±0.58 (SD))). The result that 147 out of 147 animals were effectively stun/killed using a 1-grain cartridge gives a 95% confidence interval for the true percentage of animals that would be effectively stun/killed of 97.5 to 100% with the use of the CASH small animal tool (CPK200) under the conditions of the current study (Wilson's Method [16]), and a 95% confidence interval of 93.7 to 100% for the 57 killed using the 1.25 grain cartridge. The CPK200 should be powered by a 1 grain cartridge, applied on the midline on the frontal/parietal bone. Although a 1.25 grain cartridge would also be successful, it is standard operating procedure that a cartridge that delivers more than the required power is not used as it shortens the life expectancy of the device. In addition, the higher grain cartridge produced less nasal hemorrhaging and more laceration at the application position.

4.1 Post-shot movement

Animal movement post-shot, i.e. clonic convulsions, are an expected result of an effective mechanical stun [17,18]. However, the presence of any movement, whether convulsions or agonal breathing following euthanasia on-farm, is aesthetically unpleasant for both the operator and any bystanders. Ideally an effective stun/kill would produce an immobile animal, but this is not the case in practice. The increase in the amount of post-shot movement that was associated with an increase in dead weight is likely to be related to the physical state of the casualty animals when they were shot. Smaller animals were less physically fit than larger piglets. The statistically significant longer movement times of piglets with no haemorrhage post-shot is an expected result, given that there is still an active heartbeat; the blood pressure reduction in those that bled either through laceration or nasal haemorrhage would exacerbate the reduction in available oxygen for muscle movement in conjunction with the lack of rhythmic breathing due to brain stem death. Similar research reported by Casey-Trott, et al., [19,20] found that the average duration of convulsion was 3.8 and 3.4 min, respectively, in neonatal pigs killed using a non-penetrating captive bolt. The onset of convulsions has been associated with the onset of an isoelectric EEG and is one of the symptoms of an effective stun [21,22]. Gibson, et al., [23] also suggested that an isoelectric EEG was incompatible with awareness. In addition, convulsions occur when modulation of the descending somatomotor activity from the brain, by the somatomotor cortex, is absent. Results from Terlouw, et al., [18] show that paddling and neck movements can be observed in stunned, unconscious cattle even if the spinal cord and brain are no longer connected. Therefore, the presence of convulsions, while unsettling to the operator, could potentially be a useful indicator of an effective stun and loss of residual consciousness. Additionally, presence of these convulsions and/or loss of muscle tone could potentially be used as indicators of early brain failure.

4.2 Agonal breathing

Agonal breathing, or gasping respiration in the dying animal, is the last respiratory pattern prior to terminal apnoea. The duration of the gasping respiration phase varies; it may be as brief as one or two breaths, or as a prolonged period of gasping lasting minutes or even hours. Gasping respiration is very abnormal, easy to recognise and distinguish from other respiratory patterns and, in the dying animal, will always result in terminal apnoea [23]. St John [24] states that agonal or intermittent gasping can be induced by ischaemia or hypoxia and demonstrates dysfunction of brain centres in the pons and is due to medullary mechanisms. In a previous study [11] nine (15%) of the piglets shot with a percussive gun (Zephyr EXL – Bock Industries) demonstrated agonal gasping >3 minutes post shot. These piglets were anaesthetized and visual evoked potentials (VEP's) recorded pre, and post-shot. The loss of VEP's and the isoelectric EEG following application from these animals confirmed the absence of cortical brain activity.

4.3 Brain damage

The damage to the cerebrum and cerebellum (shard plate displacement scores), and the haemorrhage within brain structures point to the action of impact pressure waves and physical trauma to the brain that would be inconsistent with normal cortical function. Terlouw, et al., [13] discusses the loss of consciousness to be associated with damage to either one or more of the cerebral hemispheres, the reticular formation or the ascending reticular activating system or the median thalamus bilaterally. The degree of trauma produced was considered sufficient to produce immediate loss of consciousness and death, a finding that has also been demonstrated elsewhere with piglets [11]. The initial concern that skull structure in neonate piglets would be insufficient to produce differential acceleration was not demonstrated due to the level of physical trauma produced by the blow.

4.4 Incidental brain lesions

An incidental finding during the *post mortem* examination of the heads was that six animals (2.97%) displayed cerebral lesions, two were consistent with proencephaly within the cerebrum resulting from lack of development or cell destruction within the cortex, occasionally due to viral infections in utero [25]. These cysts are usually surrounded by a membrane of astroglial cells that appears white (Figure 13). Two further animals displayed lesions consistent with abscess formation.

Figure 13. Neopallial cyst (proencephaly) within the brain of piglet 171 (Sagittal section).

5. Conclusions

Mechanical blunt force trauma provided by the Accles and Shelvoke Small Animal Tool using a 1 grain cartridge provides an immediate, reproducible, single shot, stun/kill of neonate piglets that may require euthanasia for reasons including disease control or production efficiencies. This immediacy of action and reproducibility improves the welfare of these animals. It is important that the behavioural signs of a proper stun/kill application are explained to operatives. It is concluded that the use of the Cash small animal tool (CPK 200), percussive stun/kill device can be recommended for neonate piglets when a shot position on the midline on the frontal/parietal bone is used together with a 1 grain cartridge. A higher grain cartridge (1.25 grain) was also found to be effective but is not recommended for general use as they cause excessive wear to gun components, in particular the recuperator sleeve (buffers).

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Author Contributions: Steve Wotton was the principal investigator and conceived and designed the experiments with Andrew Grist, who assisted with the study, performed the post mortem examinations and created this paper. Toby Knowles undertook the statistical analysis. Device velocity measurements and analysis were untaken by Jeff Lines. Charlie Mason sourced animals and farms for participation in the project.

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3.3 PAPER FOUR

Use of a non-penetrating captive bolt for the Euthanasia of neonate goats

Andrew Grist, Jeff A. Lines, Toby G. Knowles, Charles W. Mason and Stephen B. Wotton

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The use of a non-penetrating captive bolt for the euthanasia of neonate goats

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Simple Summary: With animal production systems, there is an inevitable need for the stock person to humanely kill new-born (neonate) animals, either due to disease, malformation or in instances of production efficiency (males born to a milking herd for example). At present, the standard method employed is manual killing with a blunt object or swinging the animal so that its' head contacts a hard surface such as a wall. Stockpeople do not like performing this action and it also has consequences for the animal in terms of reproducibility and ability of the stockperson. This study examines the use of a mechanical captive bolt device to produce immediate brain death in neonate goats, causing this state of irreversible brain dysfunction before the animal can feel the procedure, or the effects of the procedure. This study found that a device powered by a blank cartridge, containing a specified amount of explosive (1 grain),

when applied in a specific position on the head produced immediate brain death in neonate goats. As such, this method is considered to be a reproducible and humane method of euthanasia, as the brain is destroyed before the animal can feel the shot.

Abstract: A non-penetrating captive bolt device, powered by a 1 grain 0.22” cartridge delivering a calculated kinetic energy of 47 Joules was tested as a euthanasia method on 200 neonate goats (*Capra aegagrus hircus*) of mean dead weight = 4.425 kg (SD ± 0.4632), to assess effectiveness and shot position. Evaluation of the method was conducted using behavioural indicators of brain dysfunction followed by post mortem examination of the heads. Once correct shot position had been established, one hundred percent of 158 kids (95% confidence interval 97.5 to 100%) were successfully stun/killed with a shot position on the midline, between the ears with the chin tucked into the neck. The use of the Accles and Shelvoke “CASH” Small Animal Tool can therefore be recommended for the euthanasia of neonate goats with a 1 grain cartridge and a specific shooting position.

Keywords: Animal welfare; Euthanasia; Livestock; Mechanical killing; On-farm killing; Neonate goats

1. Introduction

Modern production methods inevitably lead to farmers and stockpersons having a requirement to humanely kill neonate goats (*Capra aegagrus hircus*) at some point in the production cycle, be it due to production efficiencies (e.g. male kids produced in a dairy herd), disease outbreak or neonatal issues affecting the viability of the animal.

One of the three desirable personal qualities of the stockperson identified by the Farm Animal Welfare Council [1] is empathy and affinity with the stock they rear; this quality means that in general they do not like undertaking euthanasia of livestock unless the animal appears ill and the euthanasia method is perceived as being pain free [2,3,4]. It also has to be considered that manual euthanasia is a skill that has issues in terms of reproducibility, and there is of course concern for the welfare of animals during training to proficiency.

Previous research (Defra funded project MH0116) has demonstrated that a mechanical stun/kill can offer an acceptable method for the humane killing of neonates and that a non-penetrating percussive device shows less variability than penetrating devices. The use of the Accles and Shelvoke CASH Small Animal Tool (CPK200) [5] with a pink coded 1.25-grain cartridge was tested on 80 goat kids and was subjectively assessed as producing a humane stun/kill (MH0116). Research in New Zealand [6,7] has demonstrated that the application of a mechanical percussive blow applied using a TED [8] butane powered, non-penetrating, captive bolt device that develops a kinetic energy (K.E) of approximately 27.8J [7] was effective at producing a humane stun/kill, provided a specific shooting position was employed. As Stunning is defined in European legislation [9] as any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death. In this paper we differentiate between recoverable (simple) stunning “loss of consciousness and sensibility without pain” by referring to it as stunning and “any process resulting in instantaneous death” by referring to stun/kill.

The detailed design and operation of the CASH Small Animal Tool is described in another paper [10]. Essentially, the device is a non-penetrating captive bolt that delivers a kinetic energy of 47 Joules using a 1 grain brown coded 0.22” calibre blank cartridge [10]. The manufacturer informed the research team that the updated device had been proofed to a 1-grain rather than the higher powered 1.25 grain pink coded cartridge as used in the previous study.

This paper reports the methods and findings of DEFRA project MH0150 to investigate the effectiveness of the Accles and Shelvoke “Cash” Small Animal Killer (CPK 200) powered by a brown 1-grain cartridge to produce a humane stun/kill in 200 neonate goat kids that were approximately ≤ 8 days old. The study was approved by the University of Bristol’s Ethical Committee and carried out under a United Kingdom Home Office Licence, and was conducted after initial testing on cadavers.

2. Materials and Methods

Experimental animals

The euthanasia method was applied to 200 British Saanen goat kids of mean dead weight = 4.425 kg (SD ± 0.4632). Saanens are the largest of the dairy goat breeds, a horned breed and are cited by the breed society as one of the greatest milk producers. Statistical advice suggests that 100% efficiency can never be absolutely proven. There will always be some small margin for error, however large the study. However, if we demonstrated for example, with 200 animals, we would be 95% confident if 100% of 200 animals were effectively stun/killed that the very maximum percentage of animals not immediately stunned/killed would be never more than 1.9%. Based on a confidence level of 95% a sample size of 200 was recommended as a sensible balance between animal use and demonstrating the degree of efficacy.

The animals used in this study were predominantly male goats that were surplus to the requirement of a dairy herd and are normally killed within their first week of life. Participating producers were instructed that any animal requiring euthanasia on welfare grounds must be immediately and humanely dealt with and not saved for the research trial. Research by Sutherland, et al. [7] assessed the effect of anatomical differences between male and female kids and the effectiveness of a non-penetrating captive bolt gun to produce a humane stun/kill. They demonstrated that there was no effect of gender on the effectiveness of the shot or the duration of convulsions produced and in addition, anatomical skull differences in this age of goat are insignificant. Therefore, we can justify the use of male kids to gain a representation of the effect of the percussive blow on both genders.

The kids were individually restrained within a non-flexible, plastic restrainer that was designed and built by Bock Industries in collaboration with the University of Bristol (Figure 1). The use of this restrainer enabled the humane kill to be completed by a single operator, a practical requirement of stockpersons, on-farm. All animals were shot once by an experienced researcher (S.Wotton) using the CASH small animal tool with a 1 grain brown coded 0.22” cartridge (Figure 2) whilst the kid was gently held down with the free hand. After shooting, behavioural indicators of brain dysfunction were assessed by the same researcher, together with subjective scoring of post shot movement based on the criteria given in Table 1. The presence of post-stun/kill movement (clonic convulsions) is an expected outcome with effective mechanical stunning, where spinal reflexes are “out of the control” of the higher centres of the brain and are thus exaggerated.

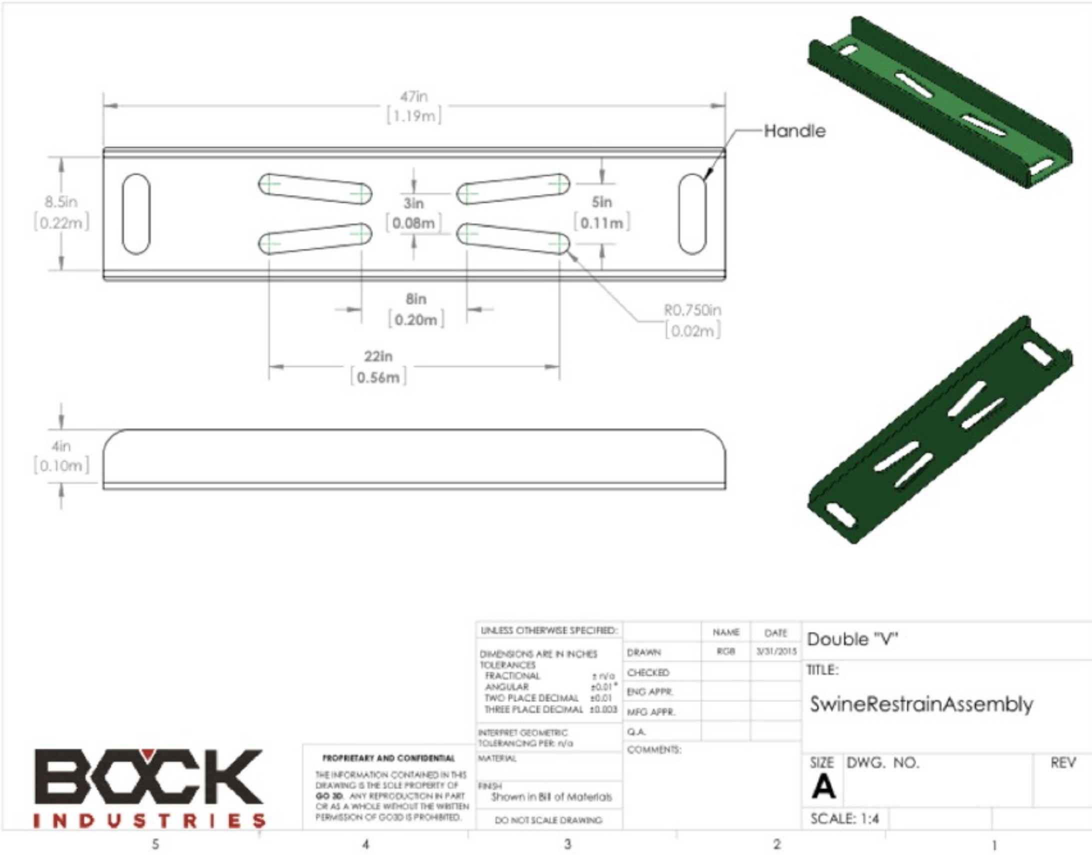


Figure 1. Bock Industries (PA, USA) Restrainer

Previous research [10,11] has shown that the following measures allow assessment of the effectiveness of the application, i.e. the absence of:

- Rhythmic breathing. This is controlled by the medulla in the brainstem and is the most reliable indicator of a stun, and if it does not return, cortical brain death (stun/kill).
- Positive corneal reflex, a brainstem reflex.
- Positive palpebral reflex, another brainstem reflex.
- Response to a painful stimulus (e.g. needle prick to the nose).

Any animal that showed signs of recovery including rhythmic breathing within a 3-minute post-application evaluation time or, that persisted beyond the 3-minute evaluation time, was killed immediately using a schedule 1 method (injected overdose of the pentobarbitone '*Euthatal'* Merial, UK GTIN:03661103015550 1ml 200mg/ml injection into the heart).

If the severity of the concussion is sufficient to affect the brainstem the animal is either stunned, dying or dead and if the absence of the above criteria persists for ≥3 minutes, the animal cannot recover [12]. Cardiac function following a severe percussive blow may persist for several minutes and is not indicative of continued brain function.

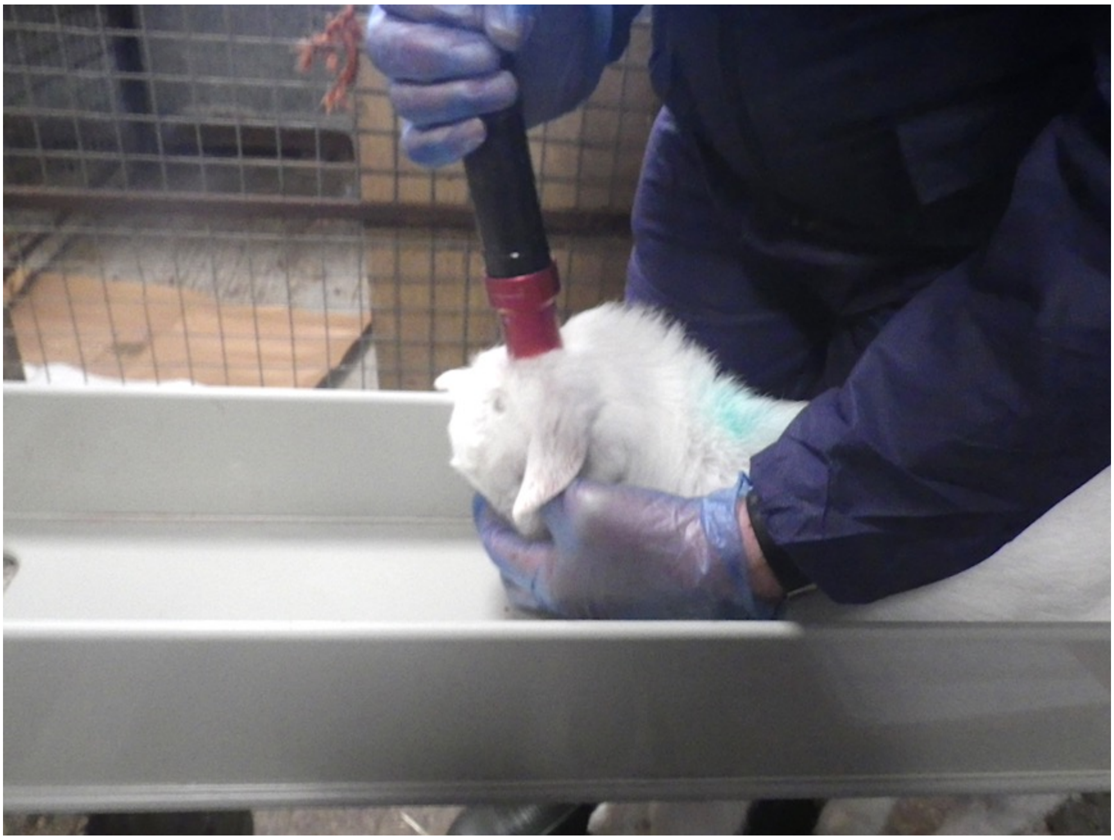


Figure 2. Restrainer in use (revised shot position technique, see below).

The presence of post-stun/kill movement (clonic convulsions) is an expected outcome with effective mechanical stunning, as previously described. As this post-shot movement may be undesirable for many operatives it was scored from 0 to 3, using the criteria shown in Table 1. Movement scoring and the time from application to the loss of movement was recorded for analysis so that training material can be developed explaining the relationship between a successful stun/kill and subsequent movement to allay any concerns that may arise from the aesthetic issues of post stun convulsions.

Table 1. Subjective scoring system used to assess post-stun/kill movement based on level of spinal reflex activity, ranging from 0 (no activity post-stun) to 3 (Gross uncontrolled physical movement).

Score	Descriptor	Description
0	No activity	Very little movement.
1	Mild activity	Some mild uncontrolled physical movement of limbs.
2	Moderate activity	Considerable uncontrolled physical movement of the limbs.
3	Severe	Gross uncontrolled physical movement

After application of the euthanasia method and assessment, each kid was numerically ear tagged with the kill number and placed in a bag before being hard frozen, pending post mortem examination to facilitate correlation between recorded behavioural indicators and post mortem findings. All assessments, and later post mortem findings, were compiled in a Microsoft Excel database for later statistical analysis.

Post mortem examination of heads

Section 1 – Post mortem examination

All experimental animals were frozen after killing and subsequently thawed for post mortem examination. The head was examined for external lesions, including laceration at the point of impact. For all carcasses, the skin from the head was removed following a T incision cranial to the shoulders and extending forward to the nose. The impact site was photographed with a digital camera (PENTAX Optio WG-1 or PENTAX K-50 (Ricoh Imaging Europe)) before removal of any haematoma and the periosteum to expose fracture lines extending from the impact site. Photographs were taken of the fracture patterns to allow for later comparison. The heads were removed from the carcasses and placed in a sequentially numbered bag with the corresponding ear tag and subsequently individually hard frozen to facilitate sectioning on the sagittal plane for photography of cranial and brain lesions to be undertaken. Freezing prior to cutting with a bandsaw prevented distortion of macroscopic lesions. To determine the most effective application position the location of each shot was recorded retrospectively during post mortem based on the lateral and sagittal guide (Figures 3 and 4) to produce a shot code for each head.

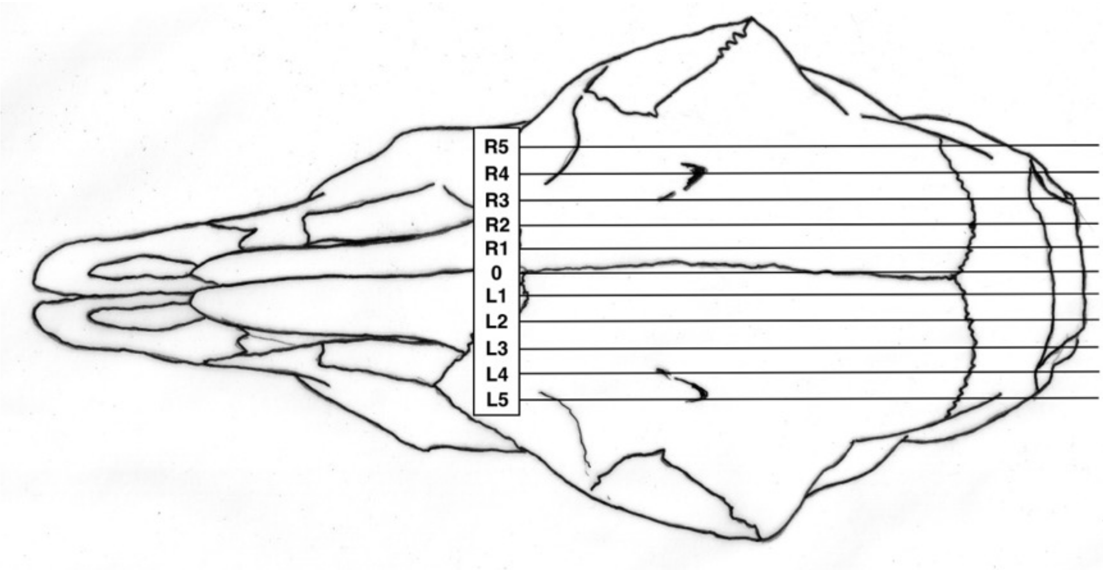


Figure 3. Diagram of lateral target area, with 0 representing the midline based on the suture of the paired frontal bones, L figures being to the left and R figures being to the right of this midline.

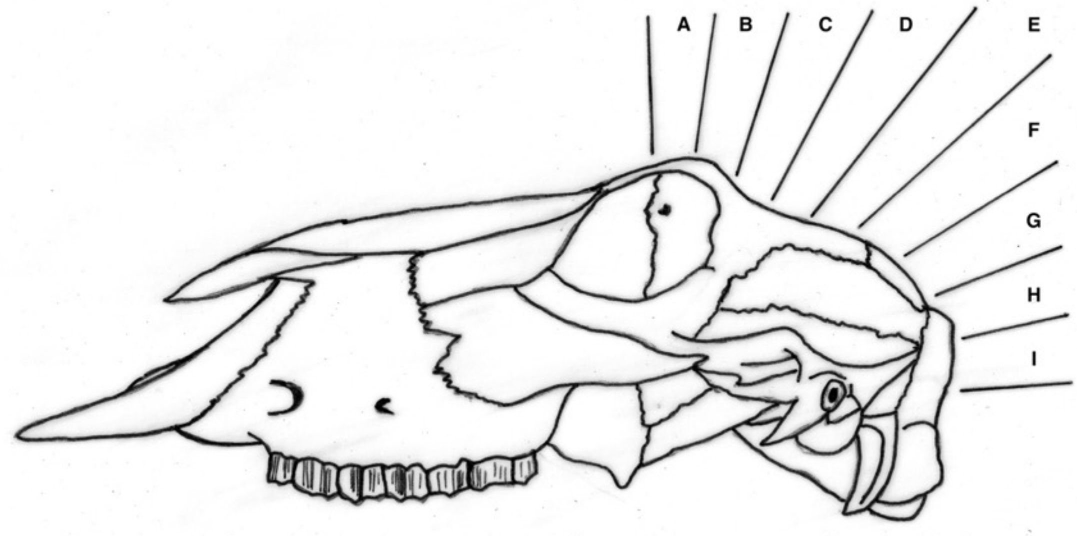


Figure 4. Diagram of sagittal targeting areas using surface topography with F representing a shot on the frontal-parietal suture, G on the parietal bone, H on the Parietal-occipital suture etc.

Each head was removed from the bag once the number had been noted; the ear tag number was checked to ensure correlation. The head was split on the sagittal plane using an electric band saw (Startrite Meat Master, UK) and both sides were photographed on the medial plane with a digital camera and post mortem findings recorded.

The macroscopic brain lesions were assessed subjectively, and blind to the weight and carcass number, utilising a scale adapted from Sharp et al., [13] and also used in Grist et al., [14] where 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The areas examined for macroscopic damage were the frontal, parietal and occipital cerebrum including the structure of the lateral ventricle and the cerebellum as detailed in Figure 5. This gave a total possible score for damage of 15. The frontal, parietal and occipital cerebrum, lateral ventricle, thalamus, pineal gland, midbrain, pons, medulla and cerebellum were also assessed for presence or absence of haemorrhaging with a score of 1 indicating presence of haemorrhage and 0 the absence of haemorrhage, giving a total possible score for brain haemorrhage of 10.

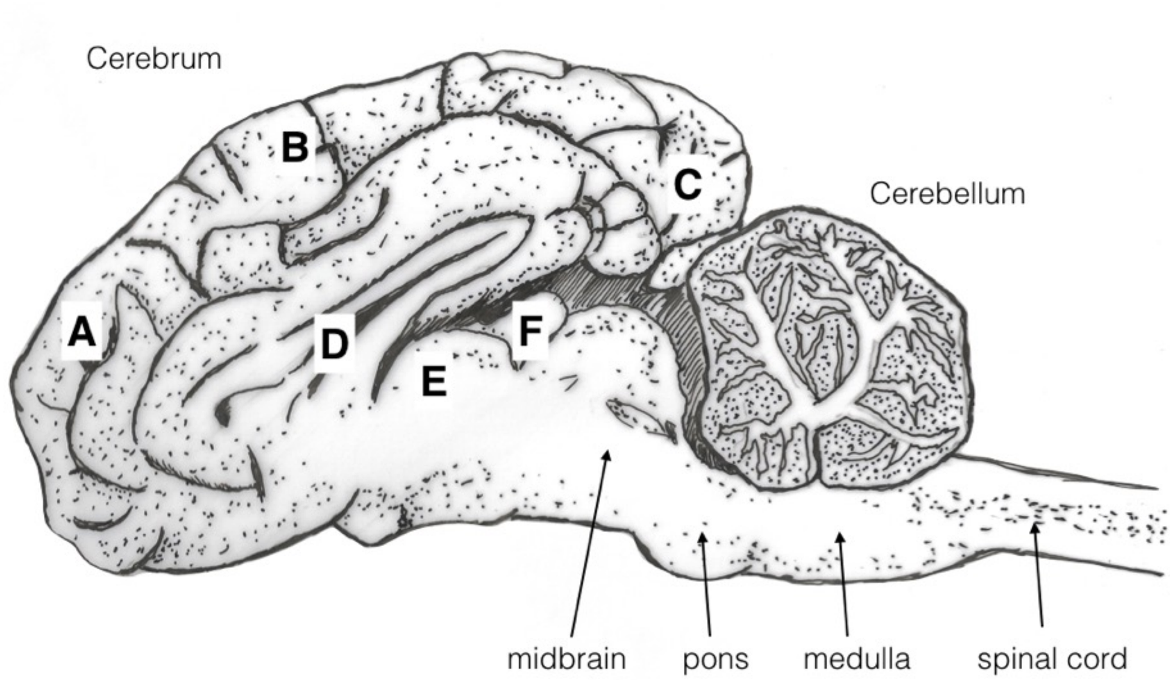


Figure 5. Sagittal diagram of a brain illustrating the areas examined for macroscopic damage. A-Frontal cerebrum, B-Parietal cerebrum, C-Occipital cerebrum, D = Lateral ventricle. These were scored on the basis of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The frontal A, parietal B and occipital cerebrum C, lateral ventricle D, thalamus E, pineal gland F, midbrain, pons, medulla and cerebellum were assessed for presence or absence of haemorrhage with a score of 1 indicating presence of haemorrhage and 0 the absence of haemorrhages.

Statistical analysis

We report simple summary statistics and a 95% confidence interval for a single sample proportion using Wilson's Method [15], for the effectiveness of the device in producing an effective stun/kill. The joint effects of variables such as carcass weight, and those describing the shot position and damage, on the two outcome variables 'time to cessation of movement' and 'movement score', were investigated using general linear models (GLM). Predictor variables were simply fitted as main effects and the residuals checked to ensure that the models met the required assumptions. The statistics package IBM Statistics SPSS (v23) was used to produce summary statistics and the GLMs. To facilitate detailed statistical analysis, the shot code for each head was converted to a number to produce a lateral and ventral position score. Using this method, the lateral score L1 became -1, L2 became -2 etc. with Right ventral positions being designated as positive scores. The ventral targeting position was converted to a numerical targeting score with A being converted to 1, B=2, C=3 etc.

3. Results

Every kid (n = 200) was effectively stunned i.e. rendered immediately unconscious. However, six of the first forty-two kids subsequently demonstrated rhythmic breathing (potentially recovering from the stun) and were humanely killed by an injected overdose of sodium pentobarbitone (Euthatal). Following the review of additional research (M. Sutherland, personal communication, 17 July, 2015), the shot position was moved further back between the ears, with the chin tucked into the neck as described by Sutherland, et al. [7], and the remaining 158 animals were shot using this revised position. Tucking the chin under the neck allows access to the rear of the head and also stretches the nuchal ligament, reducing the absorption of energy by the latter. Kids numbered 43 to 200 were successfully stun/killed (n = 2 developing agonal breathing). With our sample size of 158 kids and with 100% animals effectively stun/killed, this gave a 95% confidence interval of 97.5 to 100%.

3.1 Shot position

Figures 6 and 7 compare the distribution of application positions for the first 42 kids versus the remaining 158 animals as a heat map, clearly showing the revised and effective shot position. A heat map is a graphical representation of data where the individual values contained in a matrix are represented as colours [16].

Heat Map - Shooting positions, first 42 Kids

		Ventral Position							
		C	D	E	F	G	H	I	Total
	-4								0
	-3			1	2	1			4
	-2				4	4			8
	-1			1	7/3	2	2		12
Lateral Position	0	1			8/3	7	1		17
	1								0
	2				1				1
	3								0
	4								0
Total		1	0	2	22	14	3	0	42

Figure 6. Heat map of the distribution of application positions (right-handed operative) for the first 42 kids. Colour intensity is related to number of applications in each location. Animals euthanased by Euthatal are denoted by highlighted number, for example position -1F was applied to 7 animals, of which 3 required euthanasia due to the presence of rhythmic breathing post application. Lateral target area, with 0 representing the midline based on the suture of the paired frontal bones with positive values to the LHS and negative values to the RHS of the head (see figure 3). Ventral targeting areas using surface topography with F representing a shot on the frontal-parietal suture, G on the parietal bone, H on the Parietal-occipital suture etc. with C rostral to the head (see figure 4).

Heat Map - Shooting positions, Kids (n=158)

		Ventral Position							Total
		C	D	E	F	G	H	I	
Lateral Position	-4								0
	-3								0
	-2					7	7	1	15
	-1				2	16	14	8	40
	0				3	37	42	17	99
	1					1	2	1	4
	2								0
	3								0
	4								0
Total		0	0	0	5	61	65	27	158

Figure 7. Heat map of the distribution of application positions (right-handed operative) for the remaining 158 kids. Colour intensity is related to number of applications in each location. Lateral target area, with 0 representing the midline based on the suture of the paired frontal bones with positive values to the LHS and negative values to the RHS of the head (see figure 3). Ventral targeting areas using surface topography with F representing a shot on the frontal-parietal suture, G on the parietal bone, H on the Parietal-occipital suture etc. with C rostral to the head (see figure 4).

The first 42 animals have been removed from the statistical analysis presented below and we report only the results for the remaining 158. Figures 8 to 10 describe the distribution of dead weight (kg) mean = 4.35 kg (SD = 0.918), movements scores mean = 2.56 (SD = 0.612) and time to loss of movement (s) mean = 77.39 s (3.037), respectively for the 158 kids.

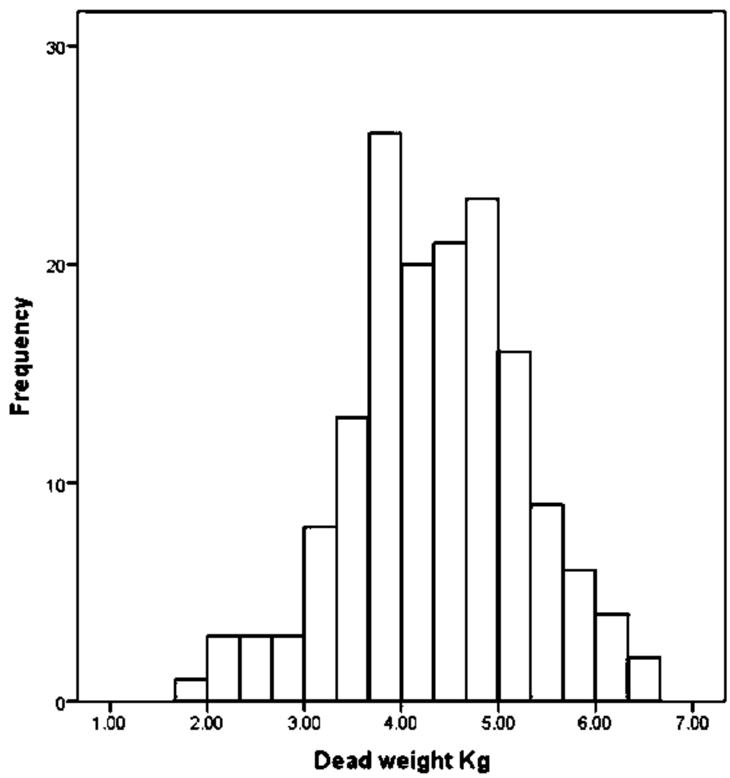


Figure 8. The distribution of kid dead weights (n = 158).

3.2 Factors related to 'time to loss of movement'

The parameter estimates from the GLM analysis of 'time to loss of movement' are shown in Table 2. This shows that there was no significant effect of dead weight, total damage score, total haemorrhage damage score or lateral shot position score on the time to loss of movement. There was a significant effect of ventral position score on time to loss of movement with every unit increase in score associated with an increased time to loss of movement of 7.96 seconds (Table 2).

Table 2. Parameter estimates from the GLM testing for an effect of dead weight (kg), total damage score, total haemorrhage score and lateral and ventral shot position scores on time to loss of movement (s).

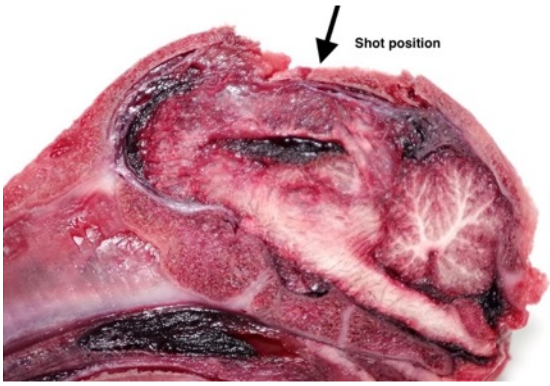
Parameter	B	S.E.	t	Sig.
Intercept	41.695	30.529	1.366	0.174
Dead Weight (kg)	-0.052	3.094	-0.017	0.986
Total damage score	-1.296	3.054	-0.424	0.672
Total haemorrhage score	-2.054	2.081	-0.987	0.325
Lateral position score	-1.978	3.895	-0.508	0.612
Ventral position score	7.960	3.648	2.182	0.031

3.3 Factors related to 'movement score'

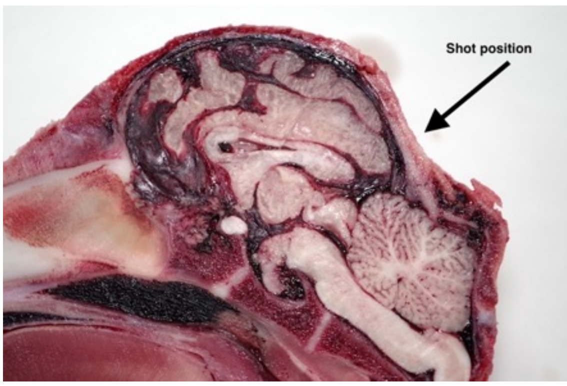
The parameter estimates from the GLM analysis of 'movement score' are shown in Table 3. This shows that there was no significant effect of total damage score, total haemorrhage score or lateral shot position score on movement score. There was a significant effect of dead weight on movement score with every 1 kg increase associated with an average increase in movement score of 0.4 (Table 3). There was a weak trend for movement score to be associated with ventral shot position score with, potentially, every 1 unit increase in ventral position score associated with, on average, a 0.1 decrease in movement score (Table 3).

Table 3. Parameter estimates from the GLM testing for an effect of dead weight (kg), total damage score, total haemorrhage score and lateral and ventral shot position scores on movement score.

Parameter	B	S.E.	t	Sig.
Intercept	1.447	0.474	3.049	0.003
Dead Weight (kg)	0.404	0.048	8.411	≤0.001
Total damage score	-0.015	0.047	-0.313	0.755
Total haemorrhage score	0.008	0.032	0.239	0.811
Lateral position score	0.083	0.061	1.373	0.172
Ventral position score	-0.098	0.057	-1.737	0.084



Kid 9. Shot position F



Kid 91. Shot position H

Figure 9 Variation in the damage produced between Kid #9 (forward shot position) and kid #91 (caudal shot position).

4. Discussion

4.1 Animal movement post shot

Once the correct shooting position had been established, the Accles and Shelvoke "Cash" Small Animal Killer (CPK 200) powered by a brown 1-grain cartridge produced an effective and humane stun/kill in all 158 (95% CI = 97.5 to 100%) of neonatal goat kids tested in the study.

When brain dysfunction is induced either by physical trauma, ischaemia or hypoxia a 'quiet' electroencephalogram is present although the carcass can display vigorous convulsions [17]. Post-shot movement is an expected outcome of an effective stun/kill as the brain is no longer suppressing spinal movements [18,19,20]. The degree of post stun movement reflected in the movement scores, recorded during this project, and the time to loss of movement, is an aesthetic concern for stockmen and any bystanders. It is proposed that both the degree and extent of post stun/kill movement will depend on factors such as the physical and nutritional condition of neonates at the time they are killed. The significant effect of ventral shot position on 'time to loss of movement' demonstrated that, as the shot position was applied more caudally, the kids displayed movement for longer post shot. It is likely that variation in shot position will affect different areas of the brain and brain stem, which will, in turn, have an effect on spinal reflexes.

The only significant factor, that affected the degree of post-shot movement, was the effect of dead weight where the heavier kids expressed more movement. The larger animals were likely to be better nourished, which could have accounted for an increase in energy available to potentiate post stun movement.

An additional outcome of this project is the production of on-line training material that will instruct stockpersons about restraint, the correct application of the gun including shot position and the expected post-shot movements (S. Wotton, personal communication, July 5th 2017).

4.2 Shooting position

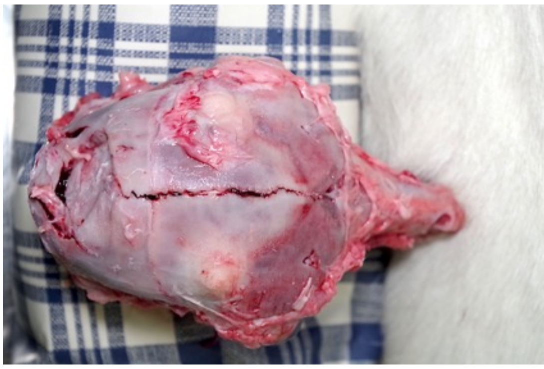
Once the optimum shooting position was determined, i.e. a position on the midline, between the ears with the chin tucked into the neck [7] (Kid 91 as shown in Figures 2, 9, &10) the method was very successful. Initial concerns that a shot placement that was caudal to the parietal-occipital suture would impact the nuchal ligament, which may absorb kinetic energy, and the possibility of shock waves affecting the medulla without affecting the reticular system or ascending reticular activating system (i.e. removing the rhythmic breathing reflex without stunning) [21] were negated by work by Sutherland et al., [7] who demonstrated loss of visual evoked potentials with this shot position, using a lower kinetic energy non-penetrating captive bolt device (27.8 Joules *c.f.* 47 Joules) (TED, BOCK Industries Inc, Philipsburg, PA, USA [8])

4.3 Brain damage

The caudal shot position (ventral position H, figure 4) employed with these animals (kids) led to less macroscopic physical damage to the cerebrum when compared with the other species (piglets and lambs) tested [10,11,14].

4.4 Fracture pattern

All the heads displayed a depressed fracture corresponding to the impact point, the fracture becoming more discrete with the caudal application adopted (Figures 10 and 11). The caudal application position also resulted in fractures extending from the impact point forward along suture lines (Figure 11)



Kid 9. Shot position F Kid 91. Shot position H

Figure 10 Variation in the fracture pattern produced between Kid #9 (forward shot position) and kid #91 (caudal shot position).

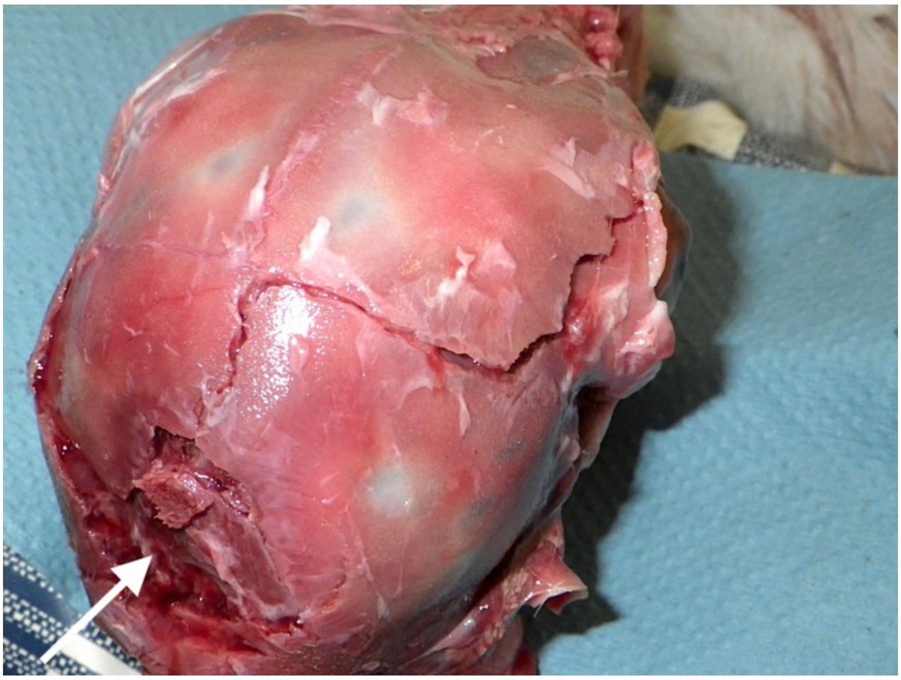


Figure 11 Extension of fracture lines following skull sutures kid #116 (caudal shot position indicated by arrow).

4.4 Agonal breathing

Of the 158 kids shot in the revised position, 2 animals (1.27%) displayed agonal breathing movements post shot, but no behavioural indicators of brain function. Agonal breathing is quite distinct from the rhythmic breathing associated with perceived consciousness [22], and has been discussed by Grist et al., [10,11,14] and is due to factors separate to those for consciousness; representing a form of residual brain stem activity that ultimately progresses to the death of the animal.

4.5 Pronecephaly

As reported in Grist et al., [10] with neonate piglets, an incidental finding during the post mortem examination of the neonate goat heads was that ten animals (5%) displayed lesions consistent with abscesses or pronecephaly within the cerebrum, the latter resulting from lack of development and destruction of the cortex, normally due to viral infections in utero [23]. These cysts are usually surrounded by a membrane of astroglial cells that appear white (Figure 12). The fact that 5% of kids presented with pre-existing macroscopic brain lesions should, in the author's view, be researched further but is outside the scope of this present study.

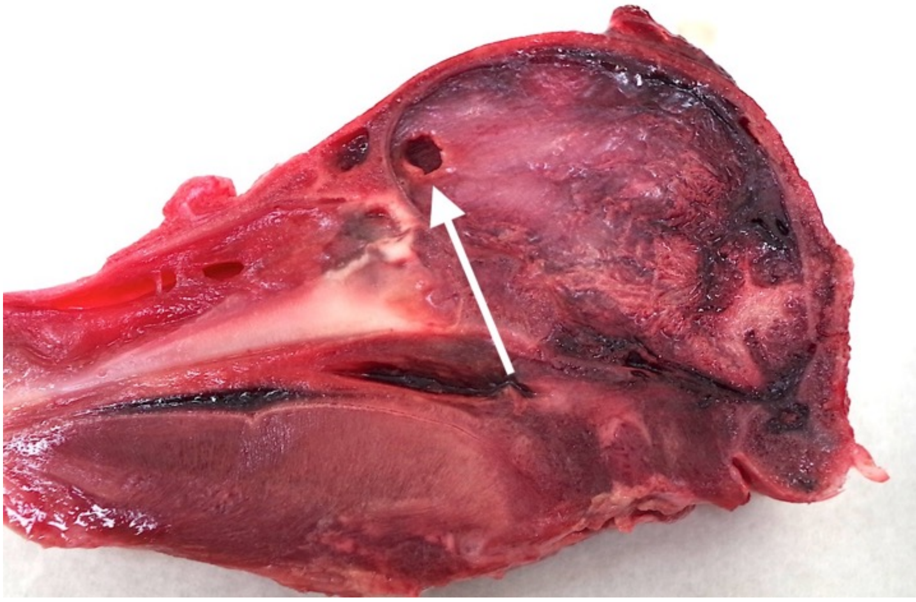


Figure 12. Arrow pointing to a neopallial cyst (pronecephaly) within the frontal cerebrum of kid number 161

5. Conclusions

It is concluded that the use of the Cash small animal tool (CPK 200), percussive stun/kill device can be recommended for euthanasia of neonate kids when a specific shot position, on the midline, between the ears with the chin tucked into the neck is used in conjunction with a 1 grain cartridge. The shot position is critical and has been confirmed by this work and the work in New Zealand by Sutherland et al., [7]. The previous work demonstrated a loss of VEP's with a weapon delivering 27.8J, the weapon used in this study produced 47J and was successful based on behavioural indicators of brain death.

Provided the correct shot position is employed, the use of this device will improve animal welfare in cases of euthanasia as it allows for reproducible results and will give the stockperson confidence in their ability to reliably produce a single use stun/kill. Post application movement will occur due to the loss of brain control of spinal reflexes and this needs to be explained to the operator.

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Author Contributions: Steven Wotton was the principal investigator and conceived and designed the experiments with Andrew Grist, who assisted with the study, performed the post mortem examinations and created the paper. Device velocity measurements and analysis were untaken by Jeff Lines. Toby Knowles undertook the statistical analysis and Charles Mason sourced animals and farms for participation in the project.

Conflicts of Interest: The authors declare no conflict of interest. Approval for the publication of this paper, including proof approval was given by the funders (Department for the environment, food and rural affairs, DEFRA, United Kingdom)

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3.4 PAPER FIVE

The Use of a Mechanical Non-Penetrating Captive Bolt Device for the Euthanasia of Neonate Lambs

Andrew Grist, Jeff A. Lines, Toby G. Knowles, Charles W. Mason and Stephen B. Wotton

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The Use of a Mechanical Non-Penetrating Captive Bolt Device for the Euthanasia of Neonate Lambs

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Simple Summary: No stockperson or producer of lamb wants or likes to euthanase their young animals (neonates). At present, there are few reliable methods of achieving a humane dispatch of a neonate lamb should it be required. In the United Kingdom, the main method used in these cases is manually impacting the head by swinging the animal against a hard surface or hitting the animal with a hard object such as a hammer. This paper examines the use of a blank cartridge powered device to stun-kill neonate lambs immediately (i.e., before the animal can feel the application). Using this method, a suitable application point and power of cartridge has been determined, providing the stockperson with a reliable and repeatable single

application method for euthanasing young lambs without the animal feeling any pain, as the device produces brain death faster than the nerve impulse can travel to the brain. This will improve animal welfare on-farm in these circumstances.

Abstract: A non-penetrating captive bolt device, powered by a 1-grain 0.22” cartridge delivering a calculated kinetic energy of 47 Joules was tested as a euthanasia method on 200 neonate lambs *(Ovis aries)* of 4.464 kg (SD (Standard deviation) ± 1.056) mean dead weight, to assess effectiveness and shot position. Every lamb (n = 200) was effectively stunned when the weapon was applied powered by a brown, 1-grain cartridge but 10/200 (5%) of the lambs displayed rhythmic or agonal breathing and were subsequently euthanased using euthatal (Merial, UK, GTIN: 03661103015550). Evaluation of the method was conducted using behavioural indicators of brain dysfunction followed by post-mortem examination of the heads. A second trial was conducted using a higher velocity 1.25-grain cartridge and a specific shot position on 48 lambs (mean dead weight = 6.21 kg, SD ± 1.24) averaging 5 days old. One hundred percent of the lambs in the second trial were immediately stun-killed. Given this complete kill rate and the sample size of the study, the study provides a statistical 95% confidence interval of 92.6% to 100%. The use of the Accles & Shelvoke “CASH” Small Animal Tool (Birmingham, UK) can therefore be recommended for the euthanasia of neonate lambs with a 1.25-grain cartridge and a specific shooting position.

Keywords: animal welfare; euthanasia; livestock; mechanical killing; on-farm killing; neonate lamb

1. Introduction

An inevitable consequence of modern production techniques is that occasionally the stockperson will be faced with the problem of euthanasia of young lamb for various reasons, such as production efficiencies (e.g., males born to a milking herd) and seriously sick young livestock that are beyond treatment. Usually, the choices that are available to them are either leaving the neonates with their mothers in the hope that they may recover, or the use of “casualty killing”. Casualty or surplus killing of young animals on-farm is usually carried out by administering a blow to the head, which is generally performed by swinging the young animal against the floor or a wall, or an impact to the head with a weighted device such as a hammer [1]. Although widely used as a means of casualty killing, the effectiveness of this method is heavily dependent on the strength and skill of the operator and, consequently, the probability of achieving an immediate kill in all cases is low. Furthermore, a lack of proper training and human error can lead to pain and distress to the animal and in addition it has to be considered that gaining proficiency in this method will take a variable period of time, during which there is the potential for animal welfare to be severely compromised. These methods are also usually aesthetically unpleasant for both the operator and any bystanders.

The Humane Slaughter Association (HSA) carried out a survey in 1996 [1], to look at the culling methods used for young lambs and piglets. The results showed that the majority of young sick lambs are left to die, whilst a manual blow to the head was the normal method applied to casualty piglets. The majority of respondents were not satisfied with their current method of casualty or surplus slaughter and all of them expressed an interest in an alternative device. At the time of the survey, there were no alternative methods available for killing young livestock.

In a previous DEFRA study (United Kingdom Department for Environment, Food and Rural Affairs, MH0116), an assessment of 240 lambs showed that there was a significant difference between the number of animals showing signs of rhythmic breathing when using different devices. The study also showed that the Accles & Shelvoke small animal tool (Birmingham, UK) was the most effective at producing a stun/kill using behavioural assessments. The trials (MH0116) were conducted using a pink 1.25-grain cartridge in the Accles & Shelvoke small animal tool and demonstrated that the gun produced an effective stun/kill with lambs (n = 80). In preparation for the current study, we were informed (Accles & Shelvoke) that the current model of the Accles & Shelvoke small animal tool was only proofed for use with brown 1-grain cartridges, and therefore we were initially unable to change to a higher strength cartridge should animals survive the treatment with a brown 1-grain cartridge.

Captive bolt devices are used widely for the humane stunning and killing of adult livestock. The device used in this study (i.e., the Accles & Shelvoke "Cash" Small Animal Killer, CPK 200) was specifically designed for the killing of large birds and has also been demonstrated, using behavioural indicators, to be suitable for the euthanasia of neonate pigs and goats [2,3], with the use on the latter species requiring a specific shot position. Finnie, et al. [4] found that the application a non-penetrating captive bolt gun to 4 to 6 week-old lambs produced sufficient traumatic brain injury to suggest that it is an acceptable method of euthanasia. In addition, Sutherland, et al. [5] demonstrated the success of a non-penetrating captive bolt gun to result in immediate insensibility and death verified by EEG assessment in neonate goats up to 48 hours of age.

This paper reports the methods and findings of DEFRA project MH0150 to investigate the effectiveness of the Accles & Shelvoke "Cash" Small Animal Killer (CPK 200), powered by a brown 1-grain cartridge, to produce a humane stun/kill in 200 neonate lambs that were approximately ≤8 days old in trial one and a second trial of 48 neonate lambs that were approximately ≤8 days old using the Accles & Shelvoke "Cash" Small Animal Killer (CPK 200) powered by a pink 1.25 grain cartridge. The trial also sought to ascertain the most effective shot position to ensure an immediate stun/kill. The weapon and its action have been described elsewhere [2]. As there are various terms used for the termination of livestock including casualty slaughter, casualty killing, dispatch, culling etc., we will, within this paper refer to 'euthanasia' as best describing an immediate stun/kill in terms of brain function.

2. Materials and Methods

2.1 Method Trial 1

A total of 200 *Ovis aries* lambs (mean dead weight = 4.464 kg, SD = ±1.056), a mixture of Friesland and Suffolk crossbreeds, were allocated to trial one. These animals were healthy male lambs that were surplus to the requirement of a dairy-sheep farm and would normally have been euthanased on-farm. The lambs (≤8 days old) were restrained in a non-flexible plastic restrainer that was designed and built by Bock Industries (Philipsburg, PA, USA) [6] in collaboration with the University of Bristol (Figure 1). Following restraint, the animals were shot with the Accles & Shelvoke small animal tool, with a 1-grain cartridge as the power source producing a calculated kinetic energy of 47 Joules.

Figure 1. Lamb held in a restrainer prior to euthanasia with light pressure.

In trial one, the shot position was systematically altered between animals to assess the required shot position to achieve a stun/kill. The shot position was initially applied in the recommended shot position for sheep when using a penetrating captive bolt gun, i.e., the highest central point of the head aiming straight down towards the angle of the jaw, and more dorsal positions were systematically applied in the event of an animal displaying any signs of continued brain function.

Following application of the shot, the animal was assessed for behavioural signs of brain function [2,3,7,8] for a period of three minutes, with any animals displaying agonal breathing being assessed for a longer period. Any animals displaying behavioural signs of continued brain function were euthanased by an injection of pentobarbital ('Euthatal', Merial, UK GTIN: 03661103015550). Signs assessed were as follows:

- The absence of rhythmic breathing—which is controlled by structures within the medulla oblongata and innervated by the reticular activating system [8].
- The absence of a positive corneal reflex—a reflex with a neural pathway that passes adjacent to and partially through the reticular formation [8].
- The absence of a positive palpebral reflex—a brainstem reflex.
- The absence of response to painful stimuli (needle prick to the nose)—a cortical arc reflex [8].

The animals were also subjectively assessed for post-shot movement (clonic activity), based on the criteria given in Table 1, and the time from shot to cessation of this activity was recorded.

Table 1. Subjective scoring system used to assess post-stun/kill movement based on the level of spinal reflex activity, ranging from 0 (no activity post-stun) to 3 (gross uncontrolled physical movement).

Score	Descriptor	Description
0	No activity	Very little movement.
1	Mild activity	Some mild uncontrolled physical movement of limbs.
2	Moderate activity	Considerable uncontrolled physical movement of the limbs.
3	Severe	Gross uncontrolled physical movement.

Once assessment was completed and the brain death of the lamb was confirmed using the absence of the behavioural signs of continued brain function described above, a sequentially numbered ear tag of kill order was attached and the lamb placed in a correspondingly numbered bag to be hard frozen pending post-mortem examination.

2.2 Method Trial 2

Following consultation with the gun manufacturers, a pink 1.25-grain cartridge was acquired and a further field trial on 50 lambs was undertaken to evaluate the performance of the gun at a higher velocity. The lambs (mean dead weight = 6.21 kg, SD = ±1.24), averaging 5 days old, were restrained in the Bock restrainer and shot with the Accles & Shelvoke small animal tool with a pink 1.25-grain cartridge producing a calculated kinetic energy of 107 Joules. The shot position selected for trial two was between the ears, with the chin tucked into the neck as described by Sutherland, et al. [5] and by Grist, et al. [3] for neonate goats.

The animals were assessed post-shot using the same descriptors as in trial one.

Once assessment was completed and the death of the lamb was confirmed, a sequentially numbered ear tag was attached and the lamb was placed in a bag to be hard frozen pending post-mortem examination.

2.3 Post Mortem Examination of Heads

All experimental animals were frozen after killing and subsequently thawed for post-mortem examination. The head was examined for external lesions including laceration at the point of impact. For all carcasses, the skin from the head was removed following a T incision cranial to the shoulders and extending forward to the nose. The impact site was photographed with a digital camera (PENTAX Optio WG-1 or PENTAX K-50, Ricoh Imaging Europe, Rungis, France) before removal of any haematoma and the periosteum, in order to expose fracture lines extending from the impact site.

Photographs were taken of the fracture patterns to allow for later comparison. To determine the most effective application position, the location of each application was recorded retrospectively during post mortem analysis, based on the lateral and sagittal guide (Figures 2 and 3), in order to produce an application code for each head. The heads were removed from the carcass and subsequently individually hard frozen in sequentially numbered bags with the corresponding ear tag to facilitate sectioning on the sagittal plane for photography of cranial and brain lesions to be undertaken. Hard freezing reduces the frictional distortion of the brain during sectioning.

Each head was removed from the bag once the number had been noted and the ear number was checked to ensure correlation. The head was split on the sagittal plane using an electric band saw (Startrite Meat Master, UK) and both sides were photographed on the medial plane with a digital camera and post-mortem findings recorded.

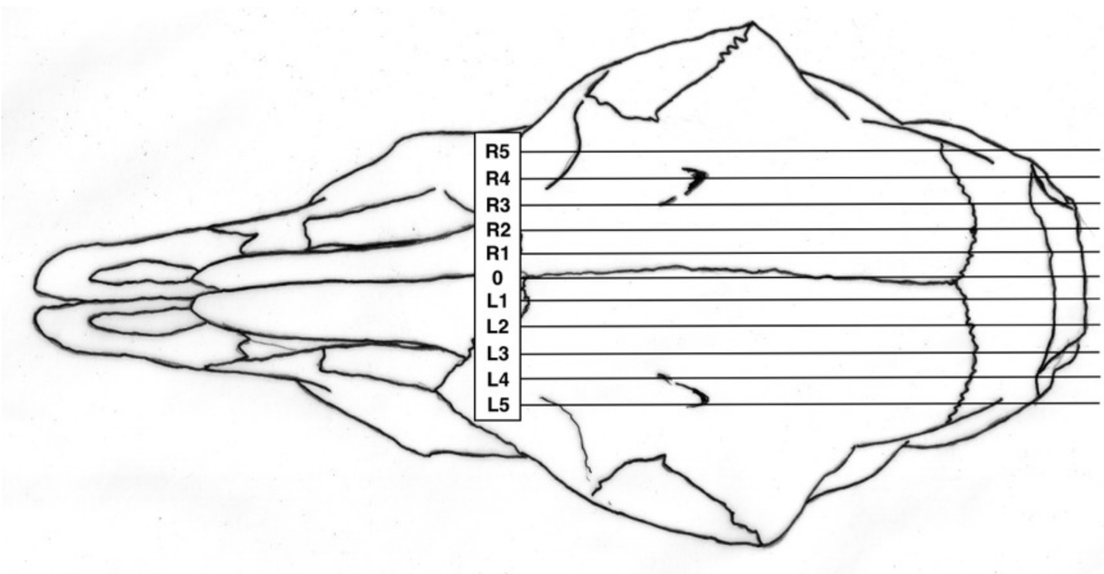

Figure 2. Lateral target area, with 0 representing the midline based on the suture of the paired frontal bones, L figures being to the left and R figures being to the right of this midline.

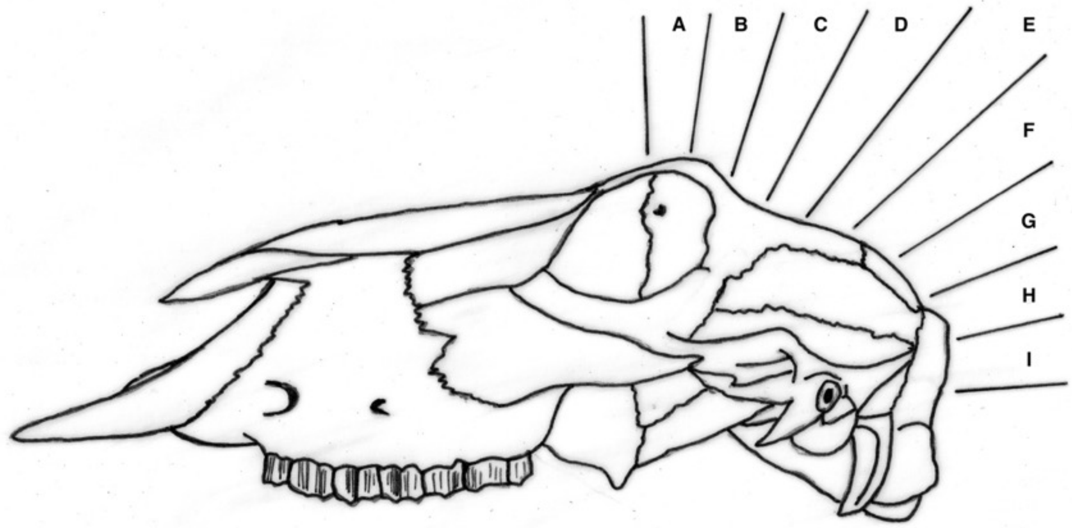

Figure 3 Sagittal targeting areas using surface topography with F representing a shot on the frontal-parietal suture, G on the parietal bone, H on the parietal-occipital suture etc.

The macroscopic brain lesions were assessed by one of the authors (AG), subjectively and blind to the weight ranges and carcass numbers, utilising a scale adapted from Sharp, et al. [9] and also used in Grist, et al. [2,3,5] where 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The areas examined for macroscopic damage were the frontal, parietal and occipital cerebrums including the structure of the lateral ventricle and the cerebellum as detailed in Figure 4. The maximum possible total brain damage score was thus 15. The frontal, parietal and occipital cerebrums, lateral ventricle, thalamus, midbrain, pineal gland, pons, medulla and cerebellum were assessed for the presence or absence of haemorrhaging, with a score of 1 indicating the presence of haemorrhage and 0 the absence of haemorrhage, giving a maximum possible total haemorrhage score of 10.

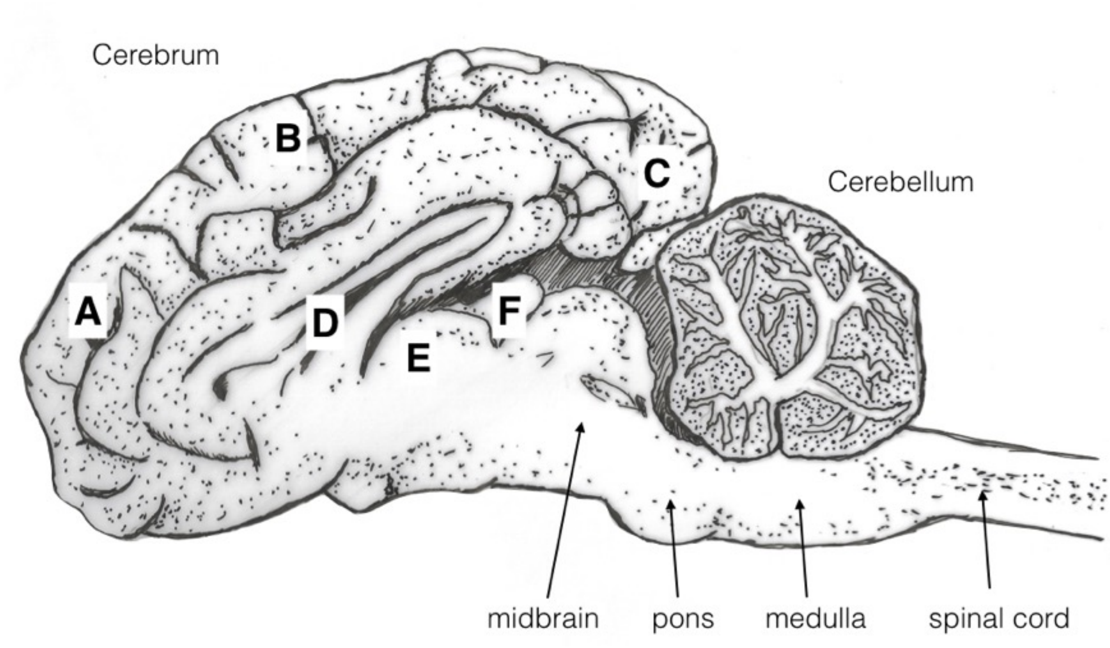

Figure 4. Diagram of a sagittal section of a brain illustrating the areas examined for macroscopic damage. Areas are labelled as frontal cerebrum (A), parietal cerebrum (B), occipital cerebrum (C) and lateral ventricle (D). These were scored on the basis of 0 = no damage, 1 = slight deformation, 2 = moderate deformation and 3 = severe deformation of the area. The frontal (A), parietal, and (B) occipital cerebrums (C), lateral ventricle (D), thalamus (E), pineal gland (F), midbrain, pons, medulla and cerebellum were assessed for the presence or absence of haemorrhages.

The shot position for each animal was also recorded based on lateral and sagittal targeting, as seen in Figures 2 and 3. These data were recorded in an Excel database (Microsoft) for statistical analysis.

2.4 Statistical Analysis

We report summary statistics below. The joint effects of variables such as carcass weight, and those describing the shot position and damage on the outcome variable ‘time to cessation of movement’ was investigated using a general linear model (GLM). Because only two values were actually recorded for the movement score the variables effecting movement score were investigated using a binary logistic regression. Predictor variables were simply fitted as main effects and the residuals checked to ensure that the models met the required assumptions. An independent *t-test* was used to test for differences between groups of lambs. Histograms of the variables were used to check that a parametric approach to testing was appropriate. IBM SPSS Statistics v23 was used for all analyses. To facilitate detailed statistical analysis, the shot code for each head was converted to a number to produce a lateral and ventral position score. Using this method, the lateral score L1 became −1, L2 became −2 etc., with right ventral positions being designated as positive scores. The ventral targeting position was converted to a numerical targeting score with A being converted to 1, B to 2, C to 3, etc.

This work was approved by the University of Bristol's Ethical Committee and carried out under United Kingdom Home Office Licence (PPL 30/2999 and PPL 30/3404).

3. Results

3.1 Trial One

Every lamb (n = 200) was effectively stunned when the weapon was applied, powered by a brown 1-grain cartridge, but 10/200 (5%) of the lambs displayed rhythmic or agonal breathing and were euthanased using euthatal. The first lamb to display agonal breathing was shot a second time, which again proved to be unsuccessful at killing the animal.

An independent samples t-test showed that the time to loss of movement was the only variable that was significantly different between the lambs that were euthanased with euthatal (not killed) and those that were effectively stun/killed ($t = 5.17$, $p \leq 0.01$). Those that were euthanased with euthatal (not killed) displayed loss of movement at

83.8 s (SE (Standard Error)= 13.99) and those that were effectively stun/killed had a mean time to loss of movement of 141.79 s (SE = 2.47). There was a trend for the ventral shot position score to differ between the two groups with a mean for those killed of 4.73 (se = 0.096) and those not killed of 3.60 (SE = 0.562) ($t = 1.986$, $p = 0.077$). The 10 lambs that were effectively stunned but not killed by the treatment were removed from further data analysis (leaving n = 190 lambs).

Figure 5 shows the time to loss of movement, for the remaining 190 lambs.

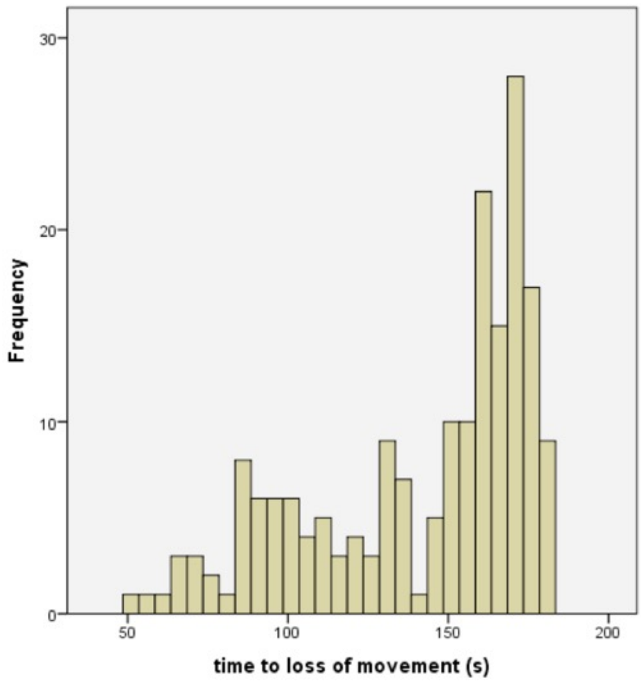

Figure 5. The distribution of time to loss of movement in lambs post-shot (mean = 141.79, SD = 34.084, n = 190).

3.1.1. Factors Related to "Time to Loss of Movement"

The parameter estimates from the GLM analysis of "time to loss of movement" are shown in Table 2. These data demonstrate that there was no significant effect of total damage score or lateral shot position score. There was a significant effect of dead weight on ‘time to loss of movement’. On average, for every additional kilogram of dead weight, there was a decrease in time to loss of movement of 7.8 s (Table 2 and Figure 6). There was a significant effect of total haemorrhage score with each unit increase in score associated with a 4.8 second decrease in time to loss of movement (Table 3 and Figure 7), and also a significant effect of ventral shot position score with each unit increase in score associated with a 4.0 second increase in time to loss of movement.

Table 2. Parameter estimates from the general linear model (GLM) testing for an effect of dead weight (kg), total damage score, lateral and ventral shot position score and total haemorrhage score on time to loss of movement (s).

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Parameter	**B**	Std. Error	***t***	**Sig.**
Intercept	182.162	18.245	9.984	0.000
Dead Weight (kg)	–7.776	2.306	–3.372	0.001
Total	0.655	1.486	0.441	0.660
Lateral Position Score	0.746	2.815	0.265	0.791
Ventral Position Score	4.026	1.941	2.075	0.039
Total Haemorrhage Score	–4.767	2.158	–2.209	0.028

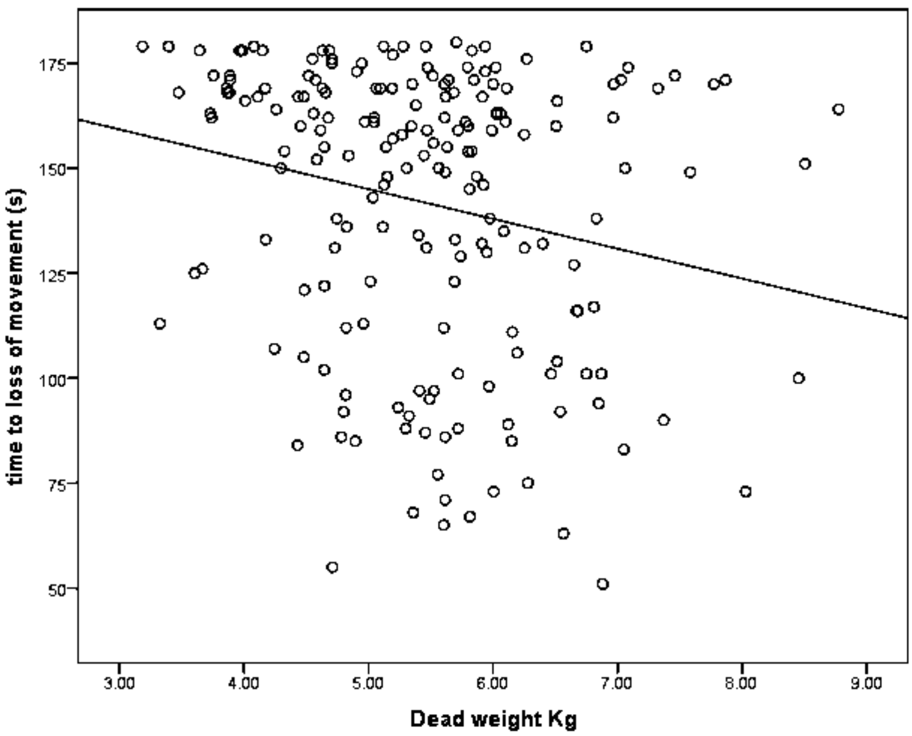


Figure 6. The effect of dead weight on time to loss of movement in lambs.

Table 3. The parameter estimates from a binary logistic regression testing the effect of variables on movement scores of 2 or 3. The regression was coded with the score of 3 as the positive (logistic) outcome.

Parameter	**B**	Std. Error	***t***	**Sig.**	**Exp(B)**
Intercept	–1.490	1.371	1.180	0.227	0.225
Dead Weight (kg)	0.967	0.202	22.989	≤0.001	2.629
Total	–.120	0.108	1.220	0.269	0.887
Lateral Position Score	–.122	0.199	0.378	0.539	0.885
Ventral Position Score	–.606	0.149	16.624	≤0.001	0.546
Total Haemorrhage Score	0.111	0.156	0.512	0.474	1.118

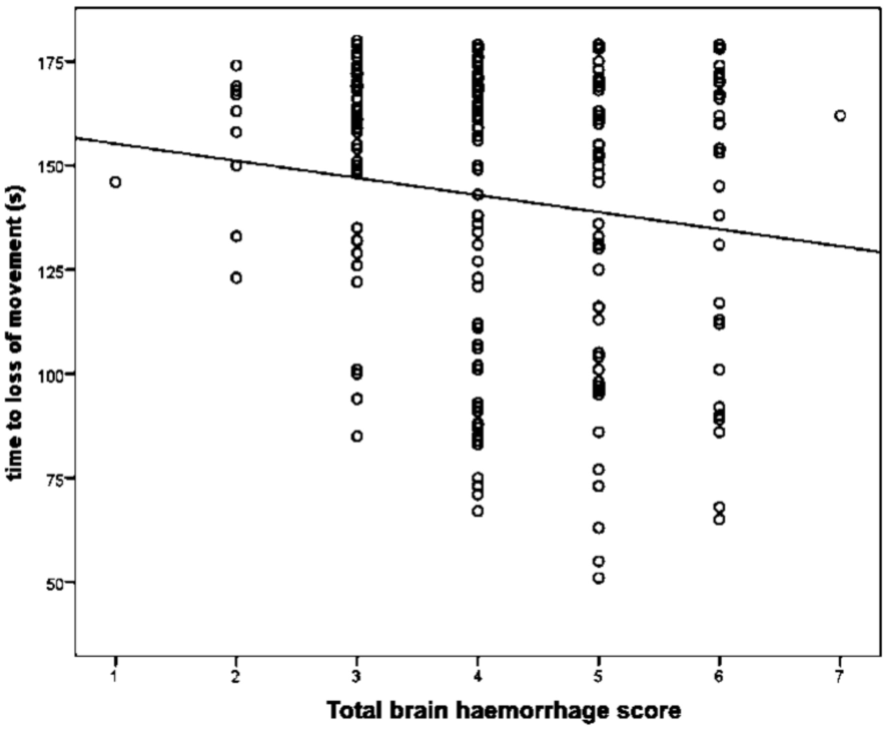


Figure 7. The effect of total brain haemorrhage score on time to loss of movement in lambs, post-shot.

3.1.2. Factors Related to 'Movement Score'

The parameter estimates from a binary logistic regression of 'movement score' differentiating between the scores of 2 and 3 are shown in Table 3. There was no significant effect of total damage score, total haemorrhage score or lateral shot position score on the probability of a movement score of either 2 or 3. There was a significant effect of dead weight and ventral shot position score. With increased dead weight, there was an increased probability of a movement score of 3 (Odds Ratio = 2.629), and with increased ventral score there was a decreased probability of a movement score of 3 (Odds Ratio = 0.546). Mean dead weight was 4.98 (SE = 0.114) kg for those with a score of 2, and 5.71 (SE = 0.093) kg for those with a score of 3. Mean ventral position score was 5.13 (SE = 0.139) for those with a score of 2, and 4.51 (SE = 0.123) for those with a score of 3.

3.1.3. General Description of Post-Mortem Findings

All animals displayed a depressed fracture of the cranial plates and concurrent subdural haematoma corresponding to the impact footprint of the convex head of the bolt. Fracture of the cranial plates was a common finding, however the deviation of the plates into the brain was less than was observed with piglets [2,7]. The lesions within the brain were dependent on the shot position with macroscopic lesions occurring under the application position. Parenchymal haemorrhages were evident within the thalamus, frontal parietal and occipital lobes of cerebrum and the cerebellum (Figure 9).

Lamb 27 (6.4 Kg)

Lamb 29 (5.115 kg)

Lamb 35 (5.28 kg)

Lamb 80 (4.905 kg)

Figure 8. Examples of post-shot trauma, medial sagittal section

3.1.4. Shot Position

The shot positions applied to neonate lambs were varied deliberately (Figures 9–11) to try to identify a position that would be 100% effective. Unfortunately, we were unable to locate such a position using the CPK200 with brown 1-grain cartridge.

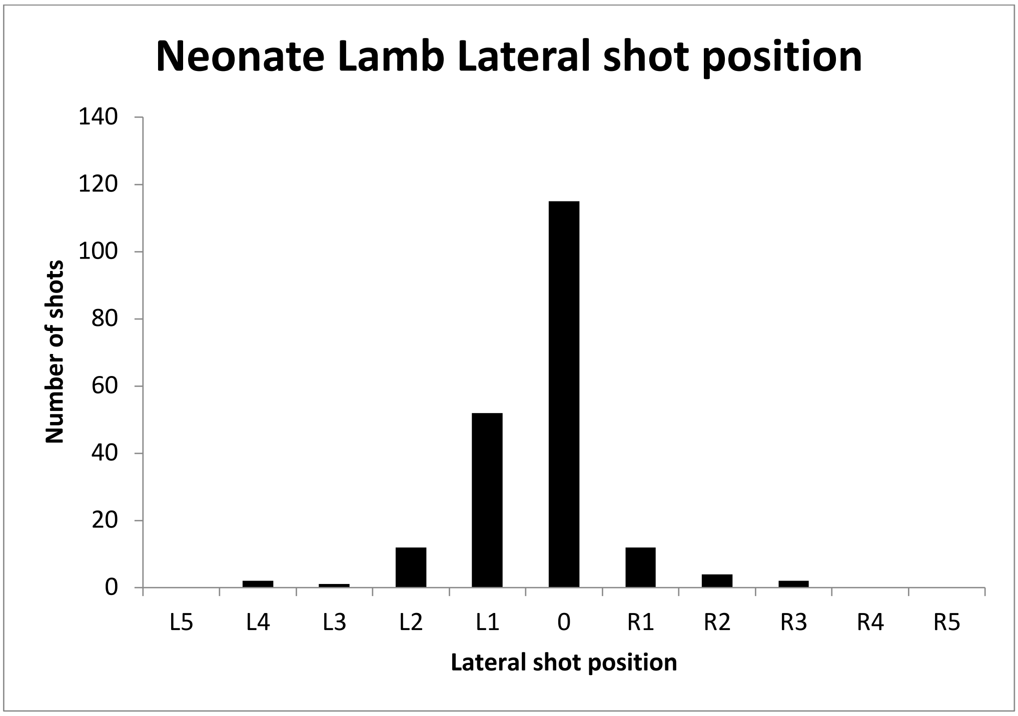


Figure 9. Graph of lateral shot position over the 200 lambs subjectively scored based on the lateral targeting position indicator in Figure 2 with 0 being on the midline, L1 being 0.5cm to the left of this line, L2 1 cm to the left of the midline etc. and the codes R being to the right of the midline viewing the head from a caudal position.

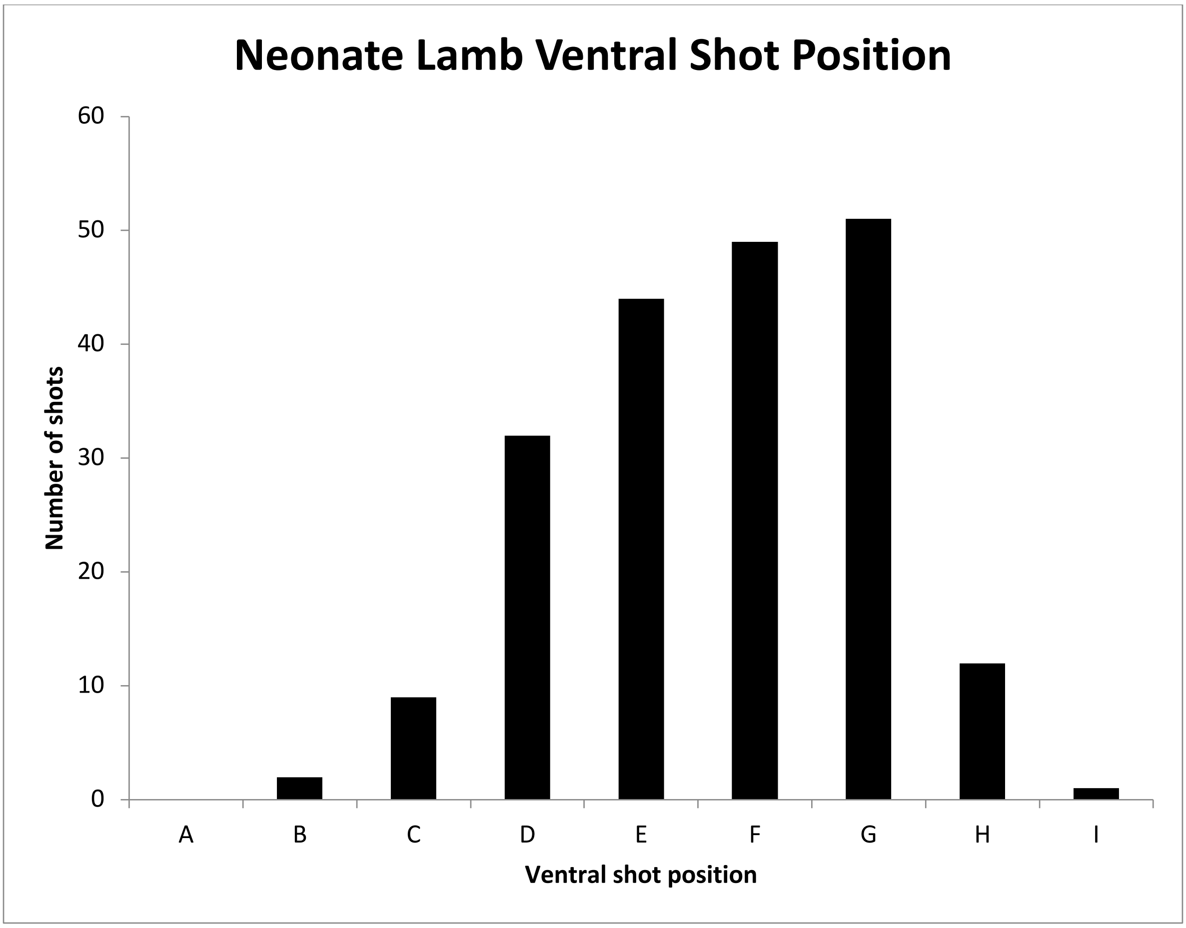
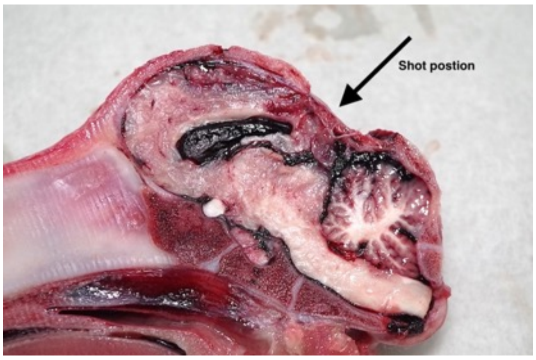


Figure 10. Graph of ventral shot position over the 200 lambs subjectively scored based on the ventral targeting position indicator in Figure 3.



Lamb 35. Shot position

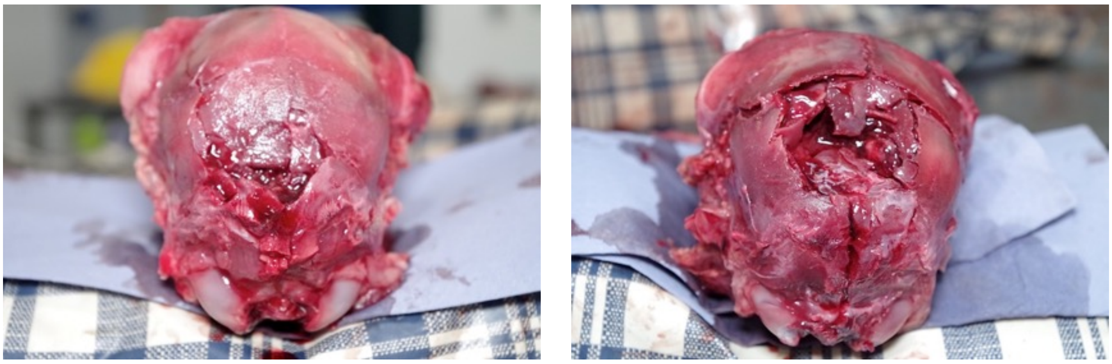
Lamb 20. Shot position

Figure 11. Variation in shot position and macroscopic brain damage in lamb head sagittal sections.

3.2 Trial 2

3.2.1 General

The deadweight of the lambs averaged 6.21 kg (SD = ±1.24). Twelve lambs (24%) produced nasal bleeding following the shot, with a further 6 (12%) having a laceration to the head. All the lambs presented with a depressed fracture of the cranium, with those shot in a more lateral position (H) tending to have a less discrete lesion (Figure 12).



Lamb 16 Shot position H   Lamb 22 Shot position F

Figure 12. Comparative effects of sagittal shot position of neonate lambs, demonstrating greater fracturing with more cranial application.

One hundred per cent of lambs in the study (n = 48) were immediately killed when the dorsal shot position, as proposed for the euthanasia of goats [3,5] (Figure 13), was applied. Given this complete kill rate and the sample size of the study, a statistical 95% confidence interval provides a very maximum percentage of animals that would not immediately be stunned/killed by this mechanical non-penetrating captive bolt system, to be at most 7.4% and at least 0%.

Figure 13. Revised shoot position for a neonate lamb. At the back of the head, on the midline, with the chin tucked into the neck, a similar position to that used for goats in Grist, et al. [3] and Sutherland, et al. [5].

3.2.2. Factors Related to "Time to Loss of Movement"

The time from application to loss of movement is shown in Figure 14. The parameter estimates from the GLM analysis of "time to loss of movement" are shown in Table 4. This shows that although there was no significant effect of total damage score on time to loss of movement (Figure 15), there was a trend (0.071) for such an effect. There were no other significant relationships.

Table 4. Parameter estimates from the GLM testing for an effect of total damage score on time to loss of movement (s).

Parameter Estimates Dependent Variable: time to loss of movement (s)						
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	70.665	4.971	14.214	0.000	60.658	80.672
Total Damage	2.283	1.236	1.846	0.071	–0.206	4.772

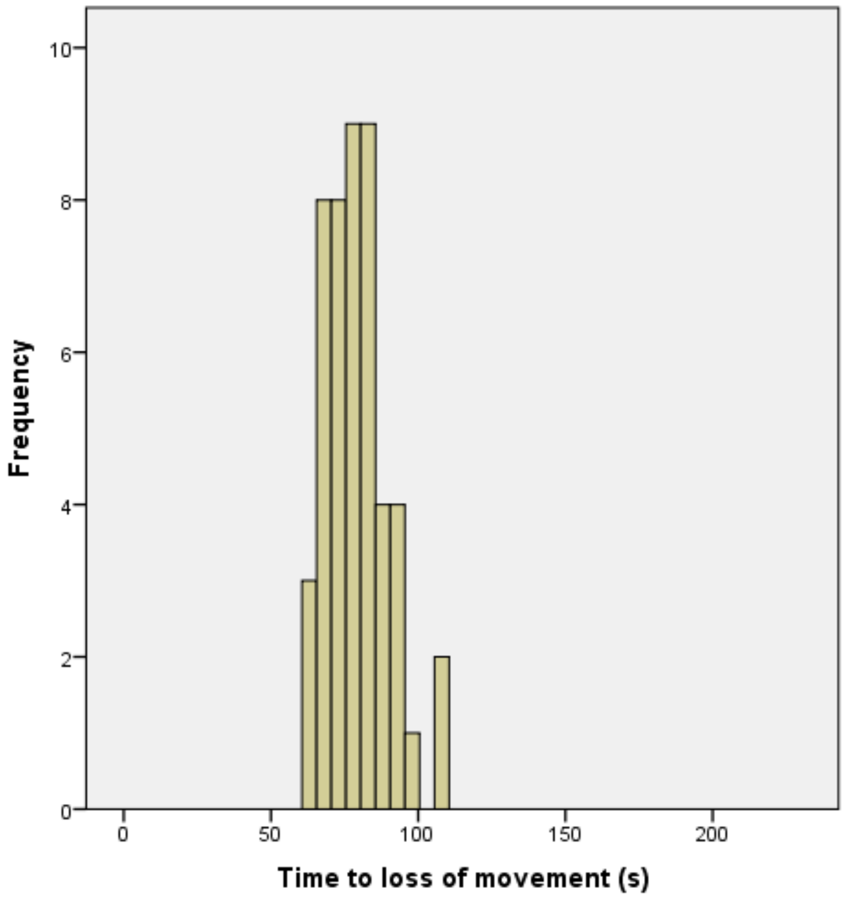


Figure 14. The distribution of time to loss of movement in lambs post-shot (mean = 79.42, SD = 10.657, n = 48).

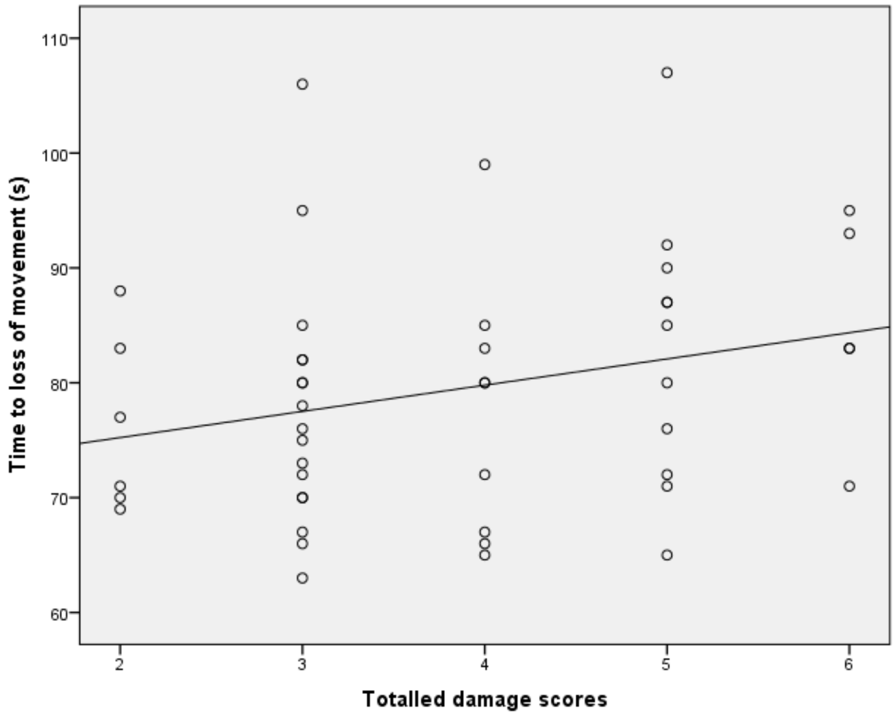


Figure 15. The "trend" for an effect (*p* = 0.071) of total macroscopic brain damage on time to loss of movement in lambs.

3.2.3. Shot Position

The first two lambs were shot in the parietal positions B:0 and C:R1, respectively. The second lamb had to be euthanased with 1 ml euthatal at 7 minutes due to the presence of rhythmic breathing. All further lambs were shot in the back of the head (E to H) as can be seen in Figure 16.

			Ventral Position						
Lateral Position	B	C	D	E	F	G	H	I	Total
-4									0
-3									0
-2						1	1		2
-1					7	9	6		22
0	1			1	6	12	3		23
1		1			1	1			3
2									0
3									0
4									0
Total	1	1	0	1	14	23	10	0	50

Figure 16. Heat map of the distribution of shooting positions for the 50 lambs. Lateral target area, with 0 representing the midline based on the suture of the paired frontal bones with positive values to the LHS and negative values to the RHS of the head (see figure 8). Ventral targeting areas using surface topography with F representing a shot on the frontal-parietal suture, G on the parietal bone, H on the parietal-occipital suture etc., with C rostral to the head (Figure 9).

The first two lambs presented with damage consistent with a parietal shot, with the major damage being to the parietal and occipital cerebrums, and no damage to the cerebellum. The second lamb displayed no macroscopic haemorrhages in the region of the midbrain, pons and medulla.

All the lambs shot in the goat position (rear of head) presented with damage to the cerebrum and haemorrhages within the pons, medulla and midbrain. Examples of damage variation according to application position are demonstrated in Figure 17.

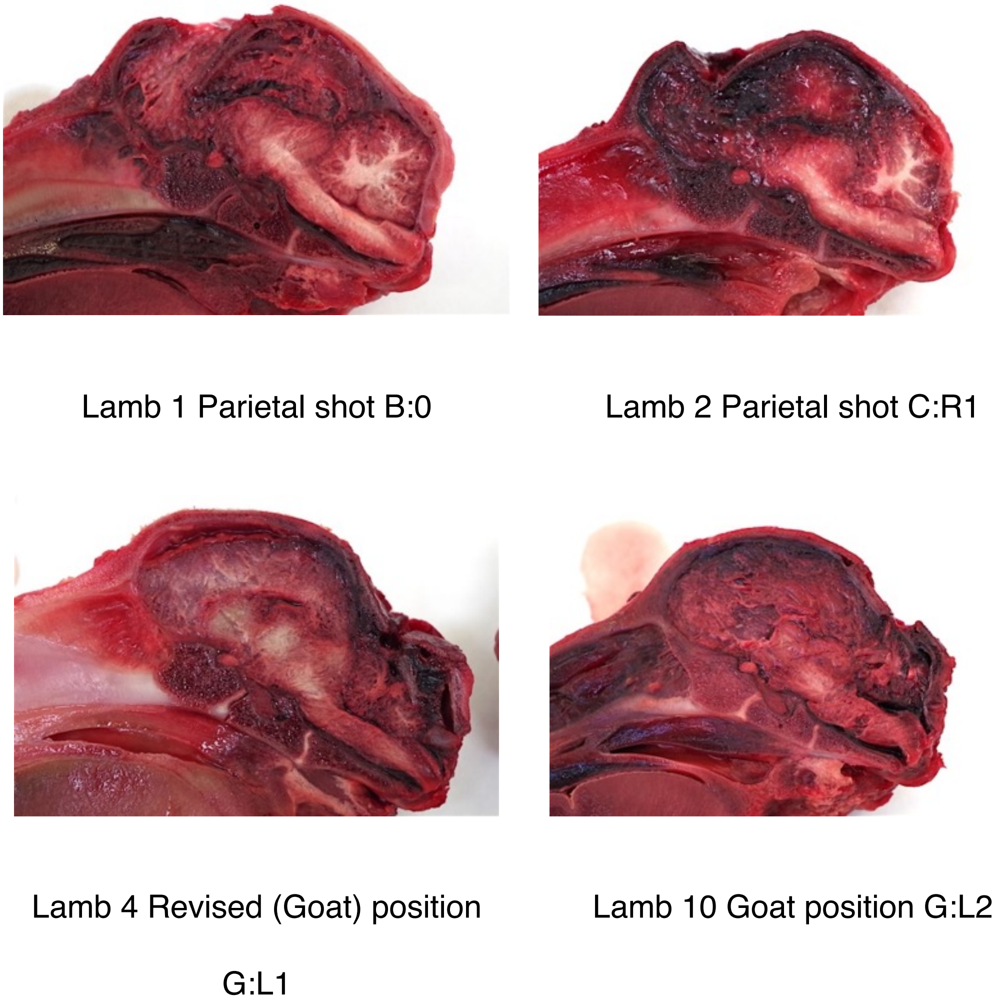


Figure 17. Trial 2 using 1.25-grain cartridges, variation in fracture indentation and brain haemorrhages based on application position.

4. Discussion

By using visual evoked potentials, Daly and Whittington [10] determined that impartation of kinetic energy to the cranium via impact of the bolt was the main determinant of an effective stun in sheep. This was borne out in the present study where all the lambs in both trials were effectively stunned, as indicated by behavioural measures.

Any method that disables brain function without simultaneously affecting the spinal cord will allow the latter to produce clonic activity. Gregory [11] stated that the loss of the modulatory control of the somatomotor cortex, demonstrated by convulsions, can be used as an indicator of early brain failure leading to death. In the case of mechanical stunning, this clonic activity has been associated with an isoelectric EEG [12,13]. Although this 'uncontrolled physical activity' post shot can be unsettling to the casual observer, once explained to the stockperson it can be used as an indicator of the success of the method in producing brain dysfunction. In trial one, the mean time to loss of movement was 141.79 s (SD = 34.084, n=196), in trial two, the mean time to loss of movement in lambs post-shot was 79.42 s (SD = 10.657, n = 48). This reduction in movement time can be attributed to various factors including the increase in applied kinetic energy from 47 J to 107 J, the increase in cartridge loading from 1-grain to 1.25-grain, the larger animals in trial two (5.45 kg, SD = 1.056 in trial one and 6.29 kg, SD = 1.192 in trial two) and the increased subjective, macroscopic brain damage score in the second trial (damage score of trial 2 = 5.44, SD = 1.78, compared with damage score trial 1 = 3.86, SD = 1.21). That there was only a trend for an effect of total damage score and no other significant variables associated with time to loss of movement in the second trial was probably due to the smaller sample size in this supplementary trial (n = 50 trial 2 compared with n = 190 in trial 1) and the greater dead weight (6.29 kg, SD = 1.192 trial 2 compared with 5.45 kg, SD = 1.056 in trial 1).

Gibson, et al. [14] found that damage to the thalamus, midbrain, pons, occipital and parietal lobe were associated with complete concussion leading to death. Finnie, et al. [4] and Terlouw, et al. [8] discuss the specific brain anatomy of sheep, in particular the effect of the tentorium cerebrelli in this species and the effect on cerebellum damage due to impact against this extension of the dura mater and the possibility of herniation through this as an added effect of a concussion wave. The shot position, recommended for goat kids [3,6], was found to be successful in this study and would direct the pressure waves directly at the tentorium and possibly directly down to the medulla and brainstem, thereby affecting the reticular activating system [6]. In this study, there was an effect of increased macroscopic total brain haemorrhage score, with each unit increase in score being associated with a 4.8 second decrease in time to loss of movement.

Intermittent, agonal gasping is distinct from rhythmic breathing and is not an indicator of consciousness [15]. The possible causes of agonal breathing in cases of mechanical stunning are discussed in Grist, et al. [2,7] and Terlouw, et al. [15]. St John [16] reviewed the current theories of the origin of normal breathing (eupnoea) proposing that eupnoea requires the control of the pons and medulla, whereas gasping is due to the effects of a latent pacemaker mechanism initiated by severe hypoxia or ischaemia, or loss of pontile and rostral medullary influences.

This infers that the presence of agonal gasping, as long as it ceases, could be considered as an indicator that the force applied to the head has produced dysfunction in the pons and medulla, and therefore the reticular activating system and ascending reticular activating system, which demonstrates a level of unconsciousness that precedes brain death [8].

The results of our study, using the standard CASH small animal tool, powered by a brown cap 1-grain cartridge, showed that the gun delivered a concussive blow of sufficient energy to produce unconsciousness in lambs. However, the percussive blow delivered by the gun did not immediately kill ten (5%) of the two hundred lambs tested.

It is proposed that the lambs that were not immediately killed had suffered severe cortical damage but insufficient damage to the brain stem to prevent the return of rhythmic breathing and other brain stem reflexes. Preliminary work carried out by Hewitt (Defra MH0116) has also suggested that the CASH Small Animal Tool was not always effective with lambs unless a higher strength cartridge (e.g., pink 1.25-grain) was used. Gibson, et al. [17] found a significant relationship between cartridge fill weight and peak velocity with the one grain cartridge and suggested that this variation may be due to the volumetric filling method of less nitrocellulose propellant with more silica filler.

As a precautionary measure, it is recommended that the use of a percussive stun-kill using a CASH Small Animal Tool with a brown 1-grain cartridge should not be used with neonate lambs. Although the lower strength cartridges (Accles & Shelvoke, 0.22 calibre, brown cap, 1-grain blank cartridge, 47 J) were found to produce an immediate stunned state, the use of behavioural indicators demonstrated this kinetic energy to be ineffective at immediately killing every animal. However, by increasing the energy of the impact by on average 60 Joules, the CASH Small Animal Tool produced an effective stun-kill in every animal that was shot in the rear of the head, the recommended shot position for goat kids [3,5]. The use of a pink 1.25-grain blank cartridge is not recommended by the manufacturer (Accles & Shelvoke) with the current weapon due to the damaging effect of this increased energy on the recuperating buffers. However, discussions with Accles & Shelvoke. have revealed that they are developing the Small Animal Tool to operate with higher energy cartridges that would meet the requirements suggested by this research.

Given the size of the second part of this study (n = 48) and the evidence that every lamb was effectively stun/killed, statistical analysis gave a 95% confidence interval of

92.6% to 100%. However, these results are supported by the first part of this study albeit using a lower cartridge strength which resulted in an effective stun in all animals (n = 200) with 10 animals displaying some signs of life post-shot and the previous research investigating the use of non-penetrating captive bolt devices on poultry [18] and neonate livestock [2,5,7]. The use of the Accles & Shelvoke "CASH" Small Animal Tool can therefore be recommended for the euthanasia of neonate lambs with a 1.25-grain cartridge and a specific shooting position. As all animals were successfully stunned by this method, should the behavioural indicators demonstrate continued brain function following the application, the authors suggest that the operative is prepared to kill the animal by pithing, via the depressed fracture, cervical dislocation, bleeding or prolonged exposure to anoxia.

5. Conclusions

Based upon behavioural indicators of brain death, the Accles & Shelvoke "CASH" Small Animal Tool is an effective single shot euthanasia device for neonate lambs, provided that a specific shot position is used, that is, on the midline at the back of the head with the chin tucked in, in conjunction with a 1.25-grain cartridge.

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Author Contributions: Stephen B. Wotton was the principal investigator and conceived and designed the experiments with Andrew Grist, who assisted with the study, performed the post mortem examinations and created this paper. Toby G. Knowles undertook the statistical analysis. Device velocity measurements and analysis were untaken by Jeff A. Lines. Charles W. Mason sourced animals and farms for participation in the project.

Conflicts of Interest: The authors declare no conflict of interest. Approval for the publication of this paper, including proof approval was given by the funders (Department for the environment, food and rural affairs, DEFRA, United Kingdom).

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Chapter Four

Examining Some Factors Affecting Mechanical Stunning of Adult Cattle

4.1 Candidate Contribution for Papers Six and Seven.

For Paper Six Andrew Grist devised the experiment following a request from an abattoir to examine a multiple shot bovine head to ascertain possible reasons for the multiple attempts. Having found that he was able to report the number of shots and possible order that later proved to be corroborated by the abattoir account from CCTV, Andrew Grist requested multiple shot cattle heads from various abattoirs to be sent to him as and when they occurred. Having been informed that enforcement bodies were penalising slaughter personnel who undertook secondary, tertiary and occasionally more shots to ensure stunning effectiveness Andrew Grist felt that further research culminating in a paper examining the factors would provide training material for abattoir staff and enforcement bodies and ultimately improve animal welfare.

Andrew Grist carried out all the postmortem examination of the cattle heads, interpreted the results and wrote individual reports for each which were sent to the respective abattoirs supplying the heads.

The Paper Six and concept were commented on by one of the journal reviewers as;

“The work is very informative and relevant for gaining a better understanding of cattle welfare at time of slaughtering, and for identifying a useful tool to improve guidance for industry. The results are interesting and the approach innovative.”

For Paper Seven Andrew Grist wanted to combine information that had been produced by two different strands of research and produce a paper that would make government agencies and industry aware that the cartridges used as a propellant for stunning devices could be a source of variation and a potential animal welfare issue. Andrew Grist was involved in the initial discussions into this research concept and contributed to the experimental design of the project in conjunction with the other authors. Andrew

Grist researched the theory of cartridge design and performance and assited in several of the experiments. Andrew Grist wrote both papers and created all the figures and tables in the journal format, which was then sent to team members for comment. Andrew Grist dealt with reviewer comments to the satisfaction of the journal prior to publication. Andrew Grist provided proof copies to the journal within the timeframes they required.

4.2 PAPER SIX

Macroscopic examination of multiple-shot cattle heads – an Animal Welfare due diligence tool for abattoirs using penetrating captive bolt devices?

Andrew Grist, Toby G. Knowles and Steve Wotton

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Macroscopic examination of multiple-shot cattle heads – an Animal Welfare due diligence tool for abattoirs using penetrating captive bolt devices?

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Simple Summary: The most common method of stunning cattle prior to bleeding in an abattoir is a penetrating captive bolt device, which is basically a piston driven forward by expanding gas produced by a blank cartridge. This creates a concussed state in the animal on impact with the skull, followed by penetration to prevent recovery by destroying key parts of the brain. The successful application of this device requires the correct cartridge strength for the species and accurate placement of the device. This paper examines the heads of animals that have received multiple shots in an attempt to ascertain the cause, to provide abattoirs with training material and an investigative tool to reduce the occurrences of multiple shots and reduce the consequent negative effects on animal welfare at slaughter.

Abstract: Ideally, the application of a penetrating captive bolt device to render cattle immediately unconscious prior to slaughter would be 100% effective. Unfortunately, due to various factors this is not always the case. This paper examined, as an initial proof of concept, twelve bovine heads which had received more than one shot from a penetrating captive bolt, collected from various abattoirs within the United Kingdom. The heads were frozen to facilitate splitting on the medial plane to prevent distortion of soft tissue and each sagittal section was examined macroscopically to ascertain if this method could be used to determine the reasons for repeated stun attempts. In 10 out of 12 heads, shot placement was the determining factor, in one other head it was felt that anatomical variation was the reason and the twelfth head demonstrated signs of gun malfunction as the likely cause. This work provides evidence for a larger trial to facilitate the production of guidance for the abattoir industry, the Animal Welfare Officer and regulators on the examination of heads as part of an investigation of failures of a mechanical stunning system and to provide training material for slaughter staff tasked with effectively stunning cattle.

Keywords: Animal Welfare, Abattoir, Animal Welfare Officer, Captive Bolt, Cattle, Due diligence, Multiple stun attempts

1. Introduction

Unless undertaking religious slaughter practice, pre-slaughter stunning of cattle is a legal requirement of both European legislation [1] and United Kingdom National Legislation [2-4]. In addition, the European Regulations include the requirement for the presence of an Animal Welfare Officer in each facility slaughtering over 1000 livestock units per annum, each bovine being 1 livestock unit [1].

The majority of bovines in the United Kingdom are stunned mechanically using penetrating captive bolt devices [5], with the exception of (a) abattoirs using systems such as the Jarvis electric system to stun-kill cattle, (b) those opting for non-stun slaughter under derogation of slaughter according to religious rite (Article 4) [1], and (c) those opting for the use of free bullets. The object of mechanical stunning is to produce a state of unconsciousness without pain which continues until cortical brain death through exsanguination or pithing [2-4].

The use of a penetrating captive bolt has been recognised as a two-stage process: 1. a concussed state following the transfer of kinetic energy from the bolt to the cranium followed by 2. the effect of penetration and subsequent withdrawal of the bolt, which can prevent recovery from the concussed state [6]. The shot is targeted to affect either the cerebral hemispheres on a large scale, the reticular formation, ascending reticular activating system or the median thalamus bilaterally [7] (Figure 1). The European Food Safety Authority [8] state that the extent of the damage determines the outcome of the application, and this is dependent on the size and shape of the head, skull structure and thickness, density and porosity of the bone at the recommended shooting site and on the equipment used.

It should be possible and desirable, to successfully stun 100% of the animals in a commercial abattoir [9,10]. Occasionally, due to various factors such as anatomical differences, gun maintenance and failure, cartridge strength [11] and condition, shot position and access to the animal, multiple shots have to be administered to an animal to ensure an effective stun [6, 10, 12-14]. Gregory et al [15] showed that a higher percentage of bulls (16%) demonstrated inadequate stunning compared with female cattle (6%). Atkinson et al [14] reviewed other papers and gave a range of between 9% and 32% of bovines that were not stunned at the first attempt [12,15]. Fries et al [16] examined 8879 cattle skulls at 2 head deboning plants, focusing on the precision of shot placement, finding that 4.0% and 3.1% of heads examined in the two plants had poor placement and that 284 (3.2%) of the total heads presented with two shot holes and 4

(0.05%) presented with 3 holes. These authors stated that 'measurements of the distance from the 'ideal' position and the penetration angle of the bolt do not reflect the efficacy of stunning.' However, their conclusion was based on post mortem examination rather than observation of the animal at the point of stun and pointed out that secondary shots may be confirmatory or due to uncertainty. However, the authors did raise the point that the position and direction of the shot may serve as an indirect control or assessment point [16]

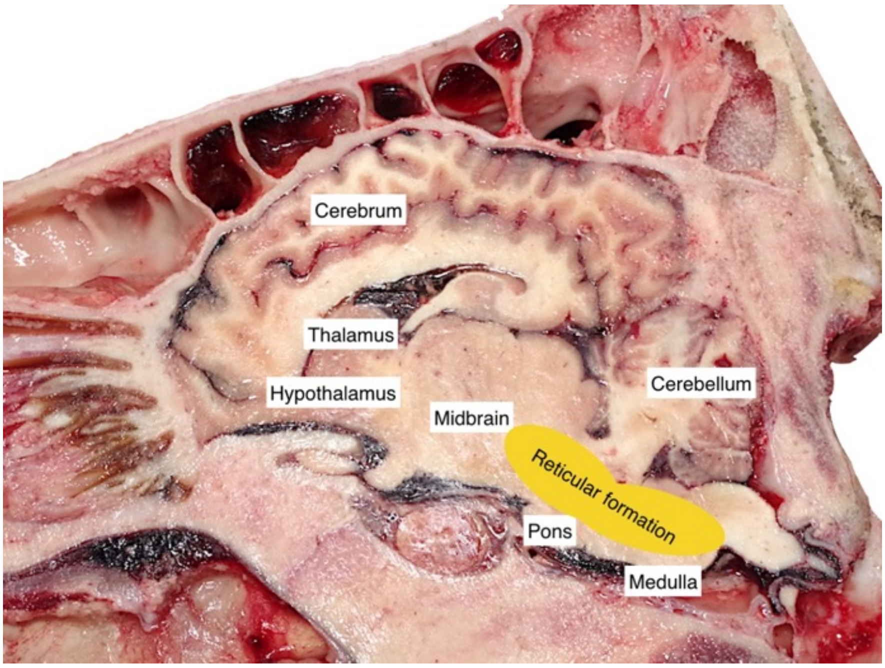

Figure 1: Position of reticular formation – Right sagittal section of bovine head (adapted from Terlouw et al [7]).

European Union and UK domestic legislation [1-4] require some form of head restraint to permit accurate stunning of an animal, however, designs vary. Von Wenzlawowicz et al [13] reported that 35% of cattle were inaccurately shot when abattoirs were not equipped with restraint devices to steady the head prior to the application of the captive bolt gun.

Council Regulation (EC) 1099/2009 on the protection of animals at the time of killing [1] requires monitoring procedures to be put in place (Article 16)[1] and also that methods should be reviewed in case of failure (Article 16)[1]. This paper introduces the concept of macroscopic examination of the sectioned heads of bovines receiving multiple applications as an additional tool that the Animal Welfare Officer or government enforcement official could use in these cases to attempt to ascertain likely reasons for these failures; in conjunction with other investigations that should be undertaken in an effort to understand and reduce the occurrences of multiple stun attempts within abattoirs. This pilot study was designed to examine the value of macroscopic examination of heads for shot position variability, anatomical variation and other factors that may contribute to the need for secondary and tertiary stun attempts as a guide for these investigations. Finnie,[17] demonstrated that penetrative captive bolt use produces a well demarcated haemorrhagic tract within the brain structure, which can be used in conjunction with exterior shot position to estimate the outcome and affected cerebral structures from each shot.

2. Materials and Methods

Twelve flayed heads from animals that incidentally received multiple shots during the course of production were sourced from five cattle abattoirs within the United Kingdom together with, when available, details of the device used, the cartridge strength, a record of the number of shots, the kill number for the day, the breed, sex and age of the animal. The animals were assessed by licenced slaughter staff during the course of their daily operation as being ineffectively stunned based on the standard accepted behavioural indicators of continued brain function used in the abattoir setting (rhythmic breathing and/or corneal reflex and/or eyeball rotation [8,18]) and were subsequently reshot until effective stunning resulted. These heads were then sent to the authors for examination. The heads were hard frozen to facilitate sectioning without lesion distortion, with an electric band saw (Startrite, Meatmaster, UK) along the sagittal plane. The cut surface was gently washed with water at room temperature from a long-nosed polyethylene wash bottle (Fisher Scientific, Leicestershire, UK) to remove bone dust. The brain and cranial cavity were examined macroscopically to ascertain shot position and wound tract, to deduce shot order. The assumption was made that the 'on target' shot tract was the terminal shot position, all others were denoted numerically or alphabetically starting at the rostral position for descriptive purposes. Heads were photographed with a Nikon D5100 digital camera (Nikon Corporation, Japan). Shot holes and trajectories were assessed using an 8mm diameter stainless steel trocar (Surgical Holdings UK, Essex, UK) to replicate the path of the captive bolt (nominal average bolt diameter = 11.9 mm). Frontal sinus thickness was measured at the point of the recommended shot position with a standard photographic ruler (Forensics Source ABFO No. 2 Sign Photo Ruler, Amazon UK). The details of kill number, age, gender, breed and frontal sinus thickness were recorded so that these variables can be included in possible future larger scale studies as possible factors in the requirement for repeated shot application.

3. Results

The findings from the post mortem inspections of the heads are detailed in Table 1, with descriptions of the findings for three of the heads, Head 8 (multiple shots due to positioning issues), Head 4 (multiple shots possibly due to anatomical variation) and Head 12 (multiple shots possible due to gun performance) reported below.

No.	Kill number	Age Months	Age Days	Sex	Breed[1]	Number of shots	Frontal Sinus Thickness	Suggested reason for multiple shots following examination
1	119	15	20	-	-	4	22mm	Position
2	112	24	10	-	-	4	27mm	Position
3	161	27	2	M	CHX	3	26mm	Position
4	111	12	19	-	AAX	4	25mm	Anatomical
5	48	15	6	M	LIMX	4	20mm	Position
6	171	82	27	F	SIMX	4	18mm	Position
7	190	137	37	M	AA	5	30mm	Position
8	108	15	27	M	BRBX	3	26mm	Position
9	82	14	17	M	CHX	5	30mm	Position
10	117	69	17	M	ST	4	13mm	Position
11	185	118	20	M	AA	3	30mm	Position
12	106	22	12	F	LIMX	3	22mm	Gun performance

Table 1. Information for heads examined by post mortem inspection. [1] Breed codes according to the British Cattle Movement Service Official cattle breeds and codes [19]. The sinus thickness is given at the midline at the ‘ideal’ shot position.

Head 8

Kill 108 British Blue Cross Male Aged

15 months 27 days - 3 Shots

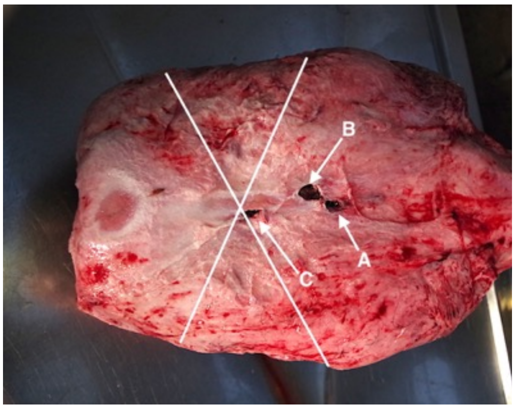

Figure 2a. *Head 8 shot placement nominal numbering for descriptive purposes. Crossed lines demonstrating 'ideal' shot position*

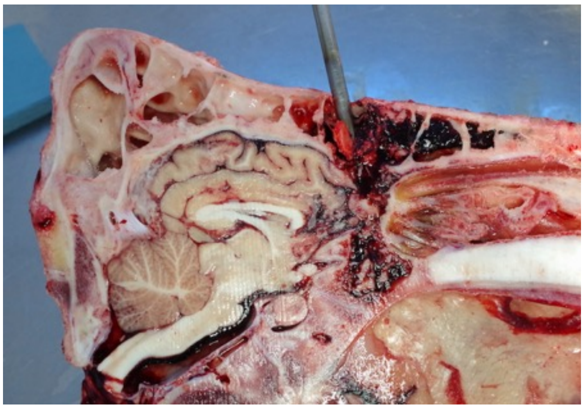

Figure 2b. *Left sagittal section. Shot A and B, trocar demonstrating tracts*

Figure 2c. *Left sagittal section, brain removed. Shot A and B, demonstrating wound tracts and bone shards (circled)*

Figure 2d. *Right sagittal section demonstrating haemorrhagic tract left by penetrating captive bolt*

The animal was reportedly shot three times (Figure 2a). On the split head, the bolt tract of shots A and B were difficult to differentiate, however both shots were positioned lower than the ideal position (Figure 2b) and followed a path that did not enter the cerebral cortex. The tract of the bolt entered through the frontal sinus, skimmed the frontal cerebrum and after passing through the sphenoidal sinus terminated in the anterior sphenoid bone. (Figure 2c). Bone shards propelled by the bolt were found in the ventral sphenoidal sinus. Shot C was positioned almost exactly at the 'ideal' shot position, at which point the sinus thickness was approximately 26mm. A second 1 cm cut was made through the right sagittal section. The bolt tract passed through the sinuses below the frontal bone and through the medial dorsal cerebrum. (Figure 2d). Petechial haemorrhages were evident within the pons and medulla. There were no abnormalities found within the cranium that would suggest other than initial shot placement as the reason for the further captive-bolt application.

Head 4

Kill 111 Aberdeen angus cross bull Aged 12 months 19 days - 4 Shots

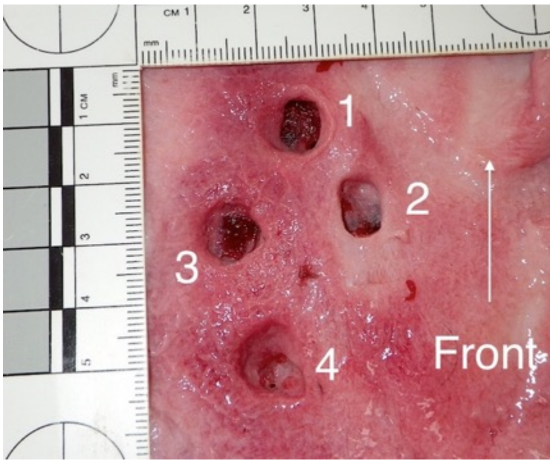

Figure 3a. *Head 4 shot placement nominal numbering for descriptive purposes*

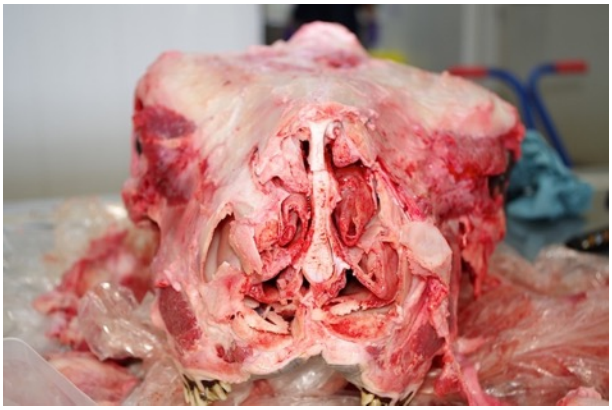

Figure 3b. *Head 4. Assymetry of head due to anatomical deformity*

Figure 3c. *Fibrous material covering the cranium, up to 5mm thick in areas*

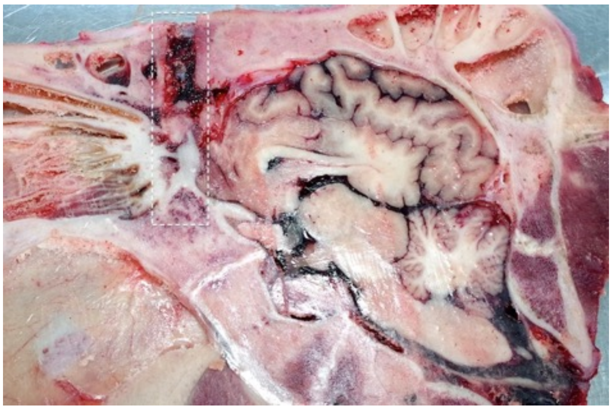

Figure 3d. *Right sagittal section. Shot 1 pathway denoted by dotted lines*

Figure 3e. *Right sagittal section Shot positions 2 and 3 pathways denoted by dotted lines*

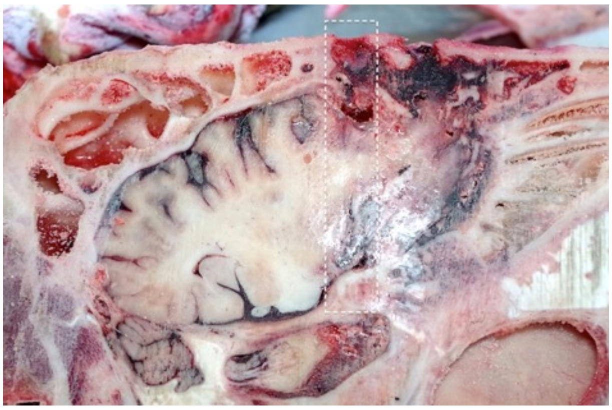

Figure 3f*. Left sagittal section. Shot 4 pathway denoted by dotted lines*

The animal had been shot four times (Figure 3a). The unusual 5mm thick covering of fibrous material over the cranial vault may have absorbed some of the impact kinetic energy reducing the effectiveness of the captive bolt device (Figure 3c). In addition, there were slight anatomical abnormalities within the skull structure that may have reduced the effectiveness and accuracy of positioning

(Figure 3b). Based on the standard model of shooting at the intersection of two imaginary lines drawn from the top of the eyes to the base of the opposite horn bud, at least two of the shots may have been more cranial than the ideal position, this may have been exacerbated by the slight elongation of the brain within the cranium. Using the nominal shot sequence based on position only: shot 1 barely grazed the fontal cerebrum and entered the dorsal sinuses and in this case based on the sagittal section, was approximately 5cm lower than a position that would penetrate the mid brain (Figures 3d, 3e). A similar effect was seen with shot 2. Shot 3 was placed approximately 2 cm caudal to shot 2 but passed through the frontal cerebrum (Figure 3e). Shot 4 was higher on the head and angled more toward the midbrain but due to the slight anatomical differences did not reach the reticular system (Figure 3f). In this case it was concluded that the first shots were placed lower than the ideal position, but that a thick subcutaneous fibrous tissue layer, combined with anatomical variation from the normal in both the skeletal structure and brain anatomy was the cause of the requirement for multiple shots. Each shot was far enough away from previous shot positions for impact on solid bone.

Head 12

Kill 106 Limousin Cross Heifer Aged 22 months 12 days - 3 Shots

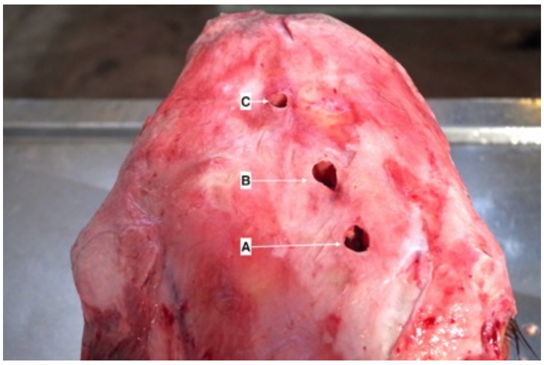

Figure 4a. *Shot numbering for descriptive purposes. Shot A denoting most rostral position and C the most caudal placement of shots*

Figure 4b. *Angle of shot A replicated by 8mm trocar*

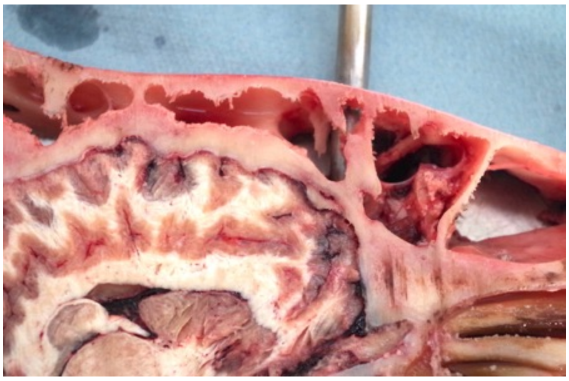

Figure 4c. *Inferred Shot A position at the level of the frontal sinus and passed into the posterior middle nasal concha. (Left sagittal section)*

Figure 4d. *Shot position B Left sagittal section*

Figure 4e. *Shot C trajectory (Left sagittal section).*

Figure 4f. *Shot C – No corresponding hole in lower frontal sinus (Left sagittal section).*

Two of the shots were positioned below the ‘ideal’ shot position (described above). The shot order lettering is purely for descriptive purposes and does not indicate an assessment of shot order (Figure 4a). Shot A was angled at 50° to the perpendicular and approximately 4 cm to the left of the midline and entered the nasal sinus (Figures 4b and 4c). Shot B was perpendicular to the head but below the ‘ideal’ position, entering the cranial vault passing through the anterior frontal cerebrum and the sphenoid sinuses and terminating in the frontal sphenoid bone (Figure 4d). Shot C was unusual in that it was in a position that would be considered appropriate (Figure 4e) but did not extend more than 2cm into the frontal sinus (Figure 4f) and did not enter the cranial vault, suggesting either a weak cartridge or the device being held at least 12.5 cm from the animals' head when fired (based on the sinus thickness being 22mm at this point and the quoted extension of the bolt being 145mm with no recuperator sleeves).

The abattoir reported that the animal went down and was released from the pen before attempting to regain posture before it was re-stunned 'freestanding'. It would appear that either shot A or C were applied when the animal was restrained in the stun box. If it was shot A this is a positioning issue however, if it is shot C it may be a failure of contact or cartridge.

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4. Discussion

This pilot study suggests that the macroscopic examination of bovine heads that receive more than one shot can provide allow reasonable conclusions to be drawn as to possible causes as part of the investigation into the need for extra shot application. In the small sample of 12 heads examined, shot position accounted for 83.33% of the repeated shots, one head presented anatomical variation (a thick fibrous layer over the cranial vault and a differing skull and brain morphology) that could account for the required extra stun attempts and one head provided evidence that one of the shots either did not have enough power due to cartridge strength or the gun was held over 10cm from the head when the shot was applied, which, given the legislative requirement for head restraint [1-4], would be an unlikely scenario. Examination of the external head after flaying (for facilitating post mortem inspection) [20] to ascertain if the animal was stunned is a flawed procedure, the assessment of a successful stun being based on behavioural indictors at the point of stunning and cannot be a retrospective act. A shot position away from the recommended position does not unequivocally relate to a poor stun and vice versa. However, if the guns are numbered and rotated so they get equal use, second stun requirements from the same gun number can be an indication of mechanical issues with that tool, so should be recorded and actioned.

The UK legislation requires that no person may use a penetrative captive bolt device to stun an animal unless…'the device is positioned and applied so as to ensure that the projectile enters the cerebral cortex' [2-4]. Terlouw et al [7] reviews our understanding of the factors that produce a stunned state which indicate that the target should be the reticular activating system and/or the ascending reticular activating system and/or the median thalamus bilaterally and/or affecting the cerebral hemispheres on a massive scale, rather than just the cortex. Several of the heads examined for this project had initial shots that entered the cerebral cortex, but in a position and angle too frontal to affect the mid brain and brain stem. The findings also support the findings of Gilliam et al [21] who suggest a higher optimum shot location to produce maximum brain stem damage and these authors would suggest that with older animals and continental breeds, especially males, that this higher position is adopted in conjunction with the highest available grain cartridge.

The post mortem findings in cases where shots were applied adjacent to each other, producing an elliptical or 'figure-eight' entrance hole (Figure 5) followed by a third shot supports the findings of Daly & Whittington [22] that the transfer of kinetic energy to an intact skull is a key requirement for a successful stun.

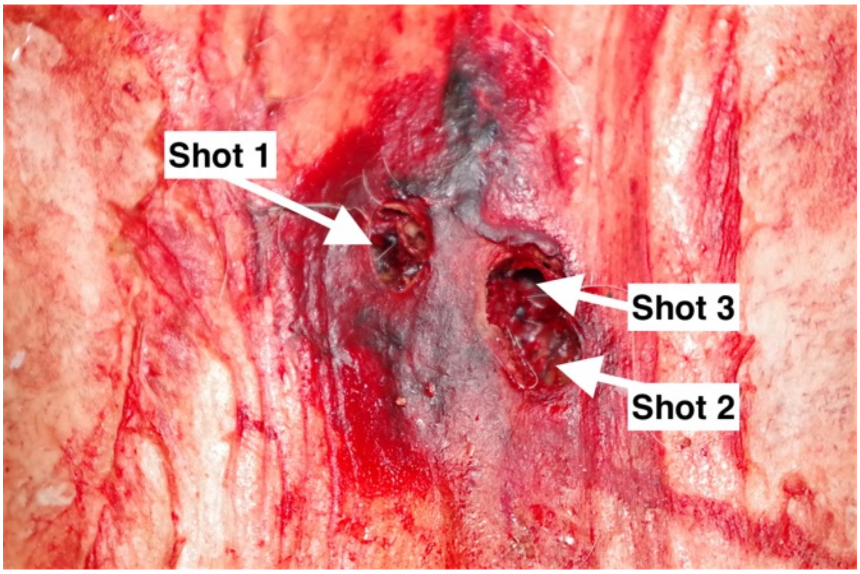

Figure 5. Figure-eight elliptical entrance wound created by shots 2 and 3 of head number 3

As a pilot study, the sample size was too small to examine the effect of kill number, gender, breed or age on the efficacy of stunning but in terms of anatomical variation, we must include consideration of animal gender, Atkinson et al [14] reported that bulls were three times as likely to receive an inadequate stun than the other cattle classes and this corresponded to the findings of Gregory et al [15]. In this study 7 of the 9 animals we received data for were male, and only 4 out of 12 animals were over 30 months of age. The sanctioning of staff who apply more than one shot simplifies a complex issue and cannot be recommended as a primary response. The welfare of the animal is an obvious priority, and repeated stun attempts are indicative of a failure of the system used and must be remedied by improvement in the system rather than by sanction; the current European legislation [1] requires monitoring of stunning and that review should be undertaken in the case of failure (Article 16) [1]. The fact that the slaughter operative recognises the requirement for, and applies, a second or further stun based on behavioural indicators or a a precautionary measure should, in the authors' view be applauded and should be undertaken without hesitation due to fear of sanction, this was raised by Fries et al [16] who questioned if some operators may avoid further shots to reduce attention to their own performance, and that the operator must be encouraged to shoot again if in doubt.

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5. Conclusions

The macroscopic examination of sectioned bovine heads, in conjunction with other investigations, can be used as an aide to assess the reasons for an ineffective stun.
If the abattoir is equipped with a freezer that would accommodate a bovine head, and access to a bandsaw, with a trained operative following health and safety procedures, it is possible to assess the probable causes for repeated stun attempts. In the European Union the bone dust and washings from the band saw would have to be treated as Specified Risk Material (SRM) [23] but this should not pose an issue as abattoirs processing adult bovines will have suitable systems in place for the storage, staining and disposal of SRM produced, as part of their standard operating conditions.
Assessment of macroscopic lesions in bovine heads can also provide training material for slaughter staff should positioning of the shot be found to be an issue, and this will improve the welfare of other animals processed by the operatives.

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Conflicts of Interest: The authors declare no conflict of interest.

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4.3 PAPER SEVEN

An examination of the performance of blank cartridges used in captive bolt devices for the pre-slaughter stunning or euthanasia of meat animals

Andrew Grist, Jeff A. Lines, Randall Bock, Toby G. Knowles and Stephen B Wotton

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An examination of the performance of blank cartridges used in captive bolt devices for the pre-slaughter stunning or euthanasia of animals

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Simple Summary: In the United Kingdom, the main method of producing unconsciousness in cattle in abattoirs is the captive bolt device. This device comprises a piston (captive bolt) which is driven into the skull of the animal at a speed that renders it unconscious before it can perceive the impact. This speed of operation combined with unconsciousness allows for humane slaughter. The piston is driven forward either by compressed air or rapidly expanding gas from a blank cartridge, with the latter being the most common method. Blank cartridges produce gas by burning propellant and are available in a range of power (more propellant produces more gas which means more

power). This paper examines variations in the performance of blank cartridges in producing sufficient velocity and therefore energy to stun animals, thereby affecting animal welfare at slaughter.

Abstract: Blank cartridges provide the power source for the majority of captive bolt devices used for rendering animals unconscious prior to slaughter within the United Kingdom or euthanasia worldwide. This paper presents the results of the examination of cartridges as one of the variables that can contribute to an unsuccessful application of this method in practice. Variation was found in cartridge weight, propellant fill volume and velocity within boxes of 1000 cartridges. The variation found was greater in lower charge (1.00 grain) cartridges than in 3.00 grain cartridges, however velocity was found to be variable in both sets. For example, in vivo velocity measurements with 0.25″ calibre 3.00 grain cartridges demonstrated an average velocity of 50.8 m/s over 200 shots with a range of 35.7 to 62.9 m/s when used in the same device. This work demonstrates that variation in cartridge performance does occur and can be due to various factors such as fill volume and propellant function, and simply weighing cartridges cannot be used to determine function, therefore cartridge performance must be a factor that is considered in the event of a miss-stun.

Keywords: animal welfare; blank cartridges; cartridge variation; captive bolt devices; mechanical stunning; performance; velocity measurement

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1. Introduction

Mechanical stunning using a captive bolt device has been used extensively to produce immediate loss of consciousness in farmed livestock and has changed little in basic design since its first inception in the Behr Flash Killer of 1904 [1]. Cartridge powered captive bolt guns are used in abattoirs for all species, either as a first-choice method, or for back-up or, in an emergency. They are also used on-farm, as a stun/kill method for poultry [2,3] and for neonate pigs, goats and lamb [4–6]. The discharge of a blank cartridge provides a chemical energy source (gas pressure via exothermic deflagration of nitrocellulose in a confined space [7,8]) to a piston or bolt which imparts kinetic energy to the cranium of the animal, to induce an unconscious state through concussion [9,10]. Therefore, both penetrating and non-penetrating captive bolt devices produce a concussed state in the same manner, via impact, the only difference being that the subsequent penetration of the bolt in the former reduces the chance of recovery from the concussed state by mechanical damage to the brain [11].

It is important that any variability between shots is reduced to a minimum, to reduce the risk of a failure to concuss/stun, with its obvious welfare implications for the animal concerned. Variables that have been recognised as a cause of variation with use include: personnel training and competence, the level of maintenance of the captive bolt device, the correct choice of cartridge for the species and size, storage of the cartridges, head restraint and positioning of the device [12–16]. This paper is focused on the examination of the effect of the variability of one of these factors, i.e., the velocity developed by the cartridge used. Gregory et al. [9] reported that with the use of penetrating captive bolt for cattle, operatives are concerned about abnormally quiet discharge noise because they suspect that the shot will have been less effective. The authors suggest that one of the likely causes of a quiet discharge is insufficient nitrocellulose (propellant) in the cartridge.

Gregory et al. [9] demonstrated that cartridges with less propellant produce less explosive noise and therefore quieter discharges, when compared with correctly filled cartridges. They reported a skew in the frequency distribution for the explosive noise measurements (dB) which indicated that about 4% of cartridges might be insufficiently filled. Gibson et al. [15] suggested that variation in cartridge fill may account for mis-stuns, especially with the lower grain cartridges. During research trials using lower grain cartridges (1.00 and 1.25 grain) for the euthanasia of neonate piglets, lamb and kids [3–5], variation in power was noted, which resulted in further investigation. This paper reports the findings of research to further investigate the variability present in commercially available cartridges, and the effect that variability may have on effective stunning.

1.1. Cartridge Description

A typical rimfire blank cartridge consists of three, separate components: the case, the primer and the propellant and no projectile. (Figure 1)

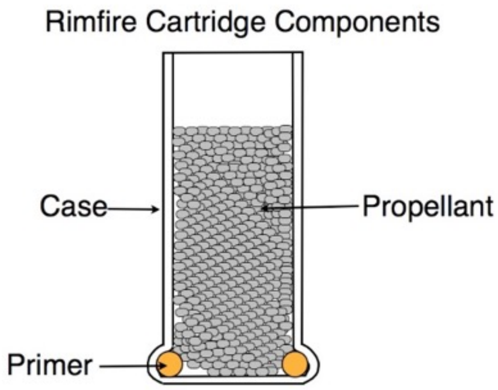

Figure 1. Rimfire cartridge components. Cross sectional diagram of an uncrimped blank cartridge.

1.2. Case

The case is usually formed from sheets of cartridge brass (copper: zinc ratio of 70:30), crimped at the end to contain the primer and propellant [17]. The crimp is colour coded with lacquer to denote the nominal charge within the cartridge, however, this is not a hermetic seal. The calibre of the cartridge is the diameter of the case, usually quoted in inches (hence 0.22″ has a nominal diameter of 5.59 mm). To facilitate ignition of the primer compound by impact from the firing pin, the case is thinner at the rim; this designed weakness restricts rim-fire cartridges to use only for low pressure applications such as blanks used in captive bolt guns and starting pistols [8].

1.3. Primer

The primer consists usually of diazole and barium nitrate and is a small quantity of an impact- and friction-sensitive high explosive (not propellant) incorporated into a bead around the base rim of the cartridge by centrifugal force. The primer is ignited by striking the rim of the cartridge, hence the nomenclature of 'rim-fire cartridge' [8]. This explosive must generate both sufficient heat and a sufficiently powerful flame to ignite the propellant which has an autoignition temperature of 170–190 °C. Voids in the primer in the rim cavity can produce misfire.

1.4. Propellant

The main propellant used in blank cartridges is 90–98% nitrocellulose, a smokeless single-base powder (as it contains one substance that produces energy) usually supplied as a fine flake powder. On combustion, smokeless powders are transformed almost entirely into gas: carbon dioxide (CO_2), carbon monoxide (CO), water vapour (H_2O), hydrogen (H_2) and nitrogen (N_2). Other chemical constituents are added to the nitrocellulose, such as graphite acting as a plasticizer and antistatic coating, potassium sulphate (K_2SO_4) added to reduce post combustion flash, diphenylamine ($C_{12}H_{11}N$) or ethyl centralite ($C_{17}H_{20}N_2O$) as a stabilizer and dinitrotoluene ($C_7H_6N_2O_4$) which acts as a surface moderant to retard the initial burning rate, initial gas generation rate and the initial flame temperature [18,19]. A sample of propellant from a typical 0.22″ blank cartridge is shown in Figure 2.

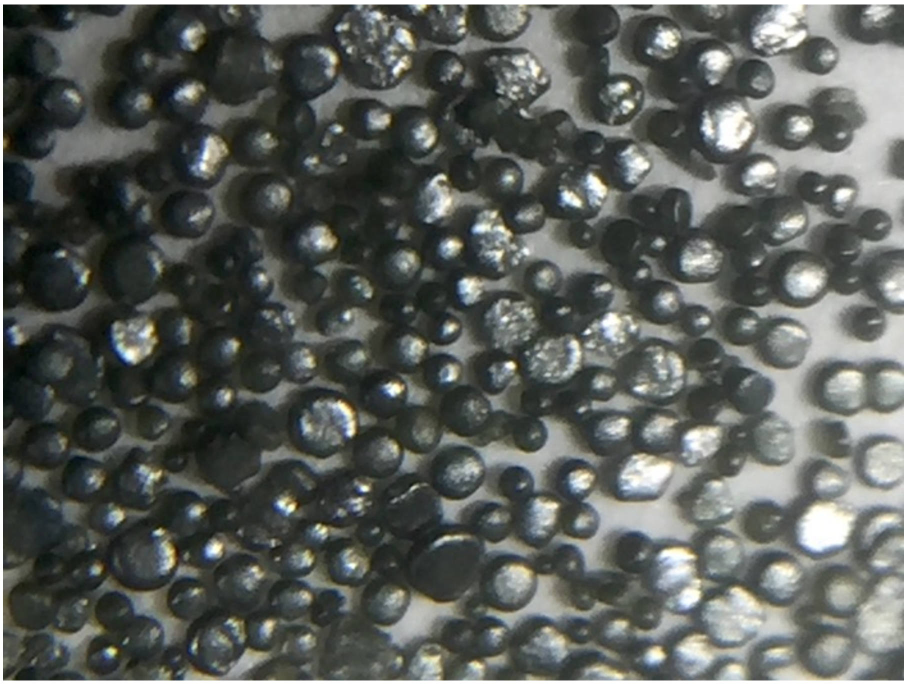

Figure 2. Propellant from a 0.22″ blank cartridge (10×).

Historically, the length of the case was altered to accommodate the propellant (Figure 3) but it is current practice for the same length case to be used for all cartridge strengths, with the void filled with a non-volatile filler such as silica [15]. Once ignited by the priming compound, the nitrocellulose deflagrates (propagation velocity below 100 m/s as opposed to detonation which occurs above 100 m/s). The propellant quantities contained in cartridges are quoted as the imperial measurement of grains (1.00 grain = 64.80 mg), with most manufacturers qualifying this measurement by quoting ‘nominal’ grain fill.

Nitrocellulose will deteriorate over time in ambient conditions due to hydrolytic and/or thermal decomposition, an important factor when considering storage of cartridges with a non-hermetic seal in damp conditions. Although nitrocellulose itself is not water soluble, many of the additives, such as potassium sulphate are, and this can affect the burn rate.

Figure 3. Temple Cox (manufacturer) 0.22″ blank cartridges: 1.00 grain cartridge on left; 2.00 grain cartridge on right.

1.6. Rationale

As one of the essential components of successful preslaughter stunning or euthanasia of animals, this paper examines commercially available cartridges to assess performance and uniformity of propellant fill weight within batches, to identify possible variation that could affect the cartridge performance and hence the ability to apply sufficient force to stun/kill every time. As part of the examination, variation in cartridge weight was assessed and then combined with velocity measurements to assess if cartridge weight could be a simple method of determining performance. This paper also discusses the possible causes of variation with cartridges.

2. Materials and Methods

This current investigation of cartridges comprises seven trials, using Accles and Shelvoke (Birmingham, UK) supplied 0.22″ and 0.25″ calibre blank cartridges for captive bolt devices taken from a batch (box of cartridges) to replicate standard use. The cartridges were within expiry dates and stored in dry conditions: Trial One—Cartridge weight, Trial Two—Cartridge weight before and after firing, Trial Three—Velocity measurement with a velocimeter, Trial Four—Velocity measurement (free flight projectile method), Trial Five—in vivo velocity measurement, Trial Six—Cartridge propellant fill volume assessment and Trial Seven—Cartridge case assessment post firing. All trial data were recorded in Microsoft Excel (Version 16.5 Microsoft Corporation, Redmond, WA, USA) for later analysis.

2.1. Trial One—Cartridge Weight

As part of the research project for the use of a non-penetrating captive bolt for the euthanasia of neonate piglets, lambs and kids, [4–6] four hundred cartridges were removed, taken from a box of 1000 Brown, 1.00 grain 0.22″ calibre cartridges and were individually weighed on a laboratory balance (Sartorius 1702 MP 8–1 Analytical Balance, Sartorius Stedim Systems GMBH, Guxhagen, Germany) with a stated precision of 0.1 mg.

2.2. Trial Two—Cartridge Weight before and after Firing

One hundred cartridges were removed from a box of 1000 green, 3.00 grain 0.22″ calibre cartridges and individually numbered and weighed twice on a laboratory balance (Sartorius ENTRIS124-1S Analytical Balance, 120 × 0.0001 g, Sartorius Stedim Biotech North America Inc., New York, NY, USA), and an average of the two weights was recorded. Each cartridge was fired (Trial Three) and reweighed; the cartridge case was subsequently cleaned with acetone and a swab and reweighed to give a measure of the residues left in the cartridge case after firing. Ninety-seven results were recorded, three results being discarded due to lack of a matching velocity measurement from Trial Three. These cartridges were selected as representative of commonly used cartridge size as the manufacturer quotes that they are suitable for medium sized animals.

2.3. Trial Three—Velocity Measurement (Velocimeter Method)

A benchtop velocimeter was developed by Bock Industries (Philipsburg, PA, USA) to provide 12 discrete velocity points over the full travel of the penetrating bolt: with a velocity data point every 4 mm for the first 7 zones and then every 8 mm for the next 5 zones (Figure 4). This velocimeter was encased in a stainless-steel housing bolted to a steel plate attached to a foam base (Figure 5). The arrangement of a paired LED emitter and sensor provided an accurate measure of velocity as the bolt passed between pairs throughout the travel after firing.

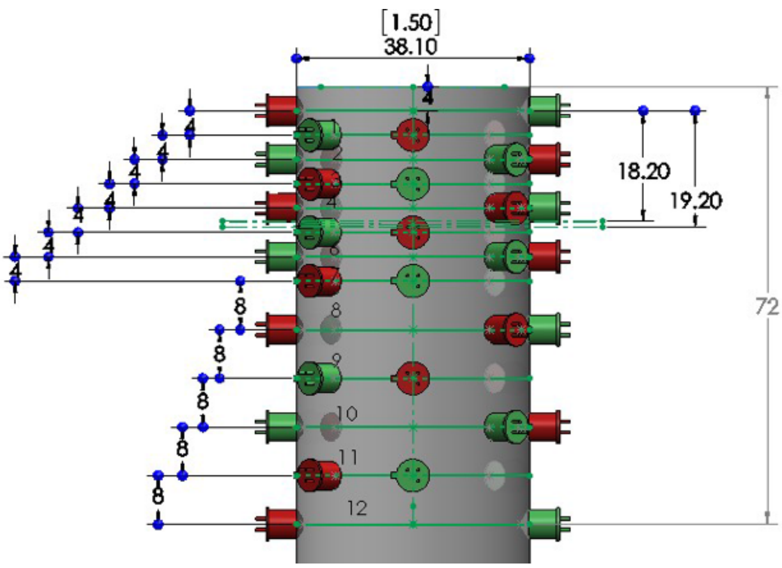

Figure 4. Diagrammatic representation of the bench velocimeter. Paired LED sensors, with green being the emitter and red being the receiver for each section. The gun to be tested is placed on the top of the velocimeter and the bolt turns on and off each LED sensor pair as it passes; the velocity of the bolt is then calculated.

Initially, ten 4.00 grain, three 3.50 grain and three 3.00 grain 0.25″ calibre cartridges were fired in an Accles and Shelvoke "Bulldozer" contact firing penetrating captive bolt device (Accles and Shelvoke, Birmingham, UK) and the velocities were measured and recorded.

One hundred 3.00 grain 0.22″ calibre cartridges were subsequently taken from a box of 1000 cartridges, weighed on a laboratory balance (Sartorius ENTRIS124-1S Analytical Balance, 120 × 0.0001 g, Sartorius Stedim Biotech North America Inc., New York, NY, USA). The cartridges were individually shot using an Accles and Shelvoke 0.22″ calibre Cash Special and the resultant velocities were measured and recorded using the benchtop velocimeter.

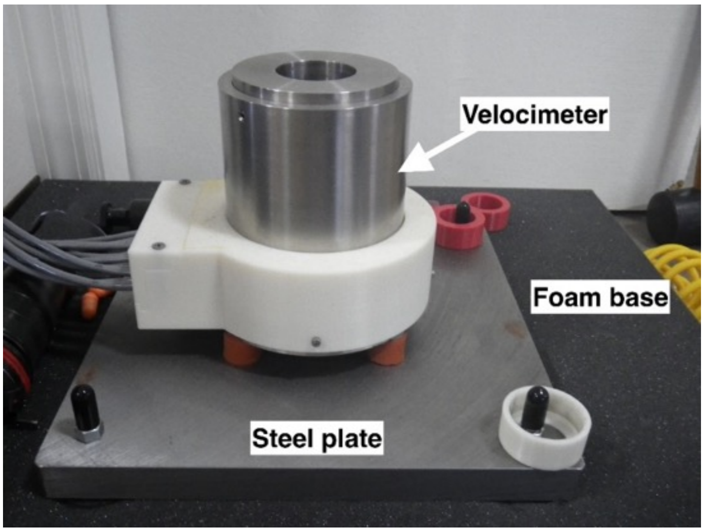

Figure 5. Velocimeter apparatus setup for firing.

2.4. Trial Four—Velocity Measurement (Free Projectile Method)

In this trial three, outwardly identical 0.22″ CASH Small Animal Tools (Accles and Shelvoke, Birmingham, UK) were used. The non-penetrating head of the bolt was replaced with a cup and a spherical projectile. The bolts and knocker heads of the three guns tested had masses ranging from 177 to 179 g. These bolts under test, with the knocker head replaced by a cup and projectile, deviated from the mass of the bolt under operational conditions by less than 1%. The guns were oriented vertically for testing so that, before firing, the projectile sat in the cup and during the acceleration stage of the bolt, the projectile was accelerated with the bolt. As the bolt began to decelerate, due to the action of the recuperating sleeves, the projectile continued at a constant velocity in free flight over the measured distance. Its velocity was subsequently measured based on the time taken to pass through a pair of infrared beams at distances of 40 mm and 60 mm from the muzzle. The kinetic energy was calculated (E_K = ½ mass x bolt velocity^2).

2.5. Trial Five—In Vivo Velocity Measurement

Two hundred bovine animals were shot using a 0.25” calibre bulldozer with green (4.50 grain) cartridges within a commercial abattoir. The baseplate of the Accles and Shelvoke “Bulldozer” penetrating captive bolt device was replaced with a prototype velocity recording device produced by Bock Industries (Philipsburg, PA, USA) as part of an ongoing research trial with the University of Bristol. Details of the velocity recording device are not produced in this paper as they are commercially sensitive.

2.6. Trial Six—Cartridge Fill Volume Assessment

Gregory et al. [9] and Gibson et al. [15] suggested there may be a variation in cartridge fill and the latter stated that silica is used to increase the fill volume of lower strength cartridges. Therefore, ten 4.00 grain and ten 1.00 grain cartridges were taken from boxes of 50 cartridges and the crimp carefully opened by hand. The propellant fill was separately emptied onto filter paper to visually compare the difference in fill volume.

2.7. Trial Seven—Case Deformity

Following the previous trials, it was noted that the cases of the spent cartridges were occasionally deformed. Deformation of the case on firing is due to excessive headspace in the device. When a rimfire cartridge is placed within the breech, the rim prevents the cartridge from fully entering the breech. The headspace is the distance between the breech and the firing pin (Figure 6). On firing, the cartridge is exposed to a rearward force equal to the pressure wave emanating from the front of the cartridge. This force will 'seal' the cartridge within the chamber to allow the expanding gas to propel the bolt forward. If there is excessive headspace, the cartridge is allowed to travel backward in the device and can deform. This rearward movement also increases the expansion chamber volume which will in addition, affect velocity, as was found in military weapons [20]. Random cartridge cases were examined after firing in Trial Three for deformation that could indicate rearward movement.

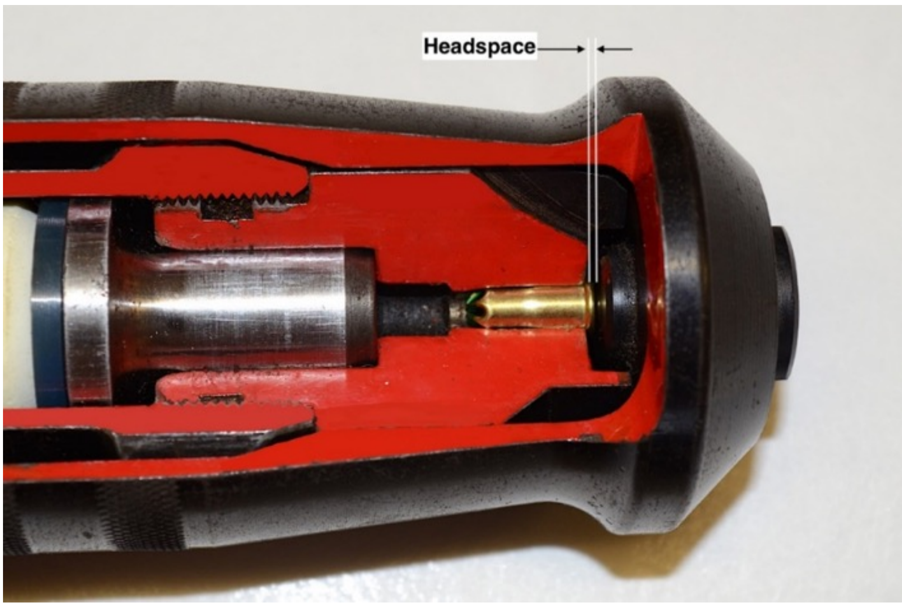

Figure 6. The headspace is the distance between the cartridge and the firing pin block (cross sectional model of an Accles and Shelvoke 'Cowpuncher' 5413R 0.22″ calibre contact firing penetrating captive bolt device).

2.8. Data Analysis

Results are reported using simple descriptive statistics and graphically, where appropriate, to show frequency distribution.

3. Results

3.1. Trial One—Cartridge Weight (1-Grain—Brown Cap 0.22″ Calibre)

The distribution of the 1.00 grain cartridge weights followed a bimodal normal distribution (Figure 7).

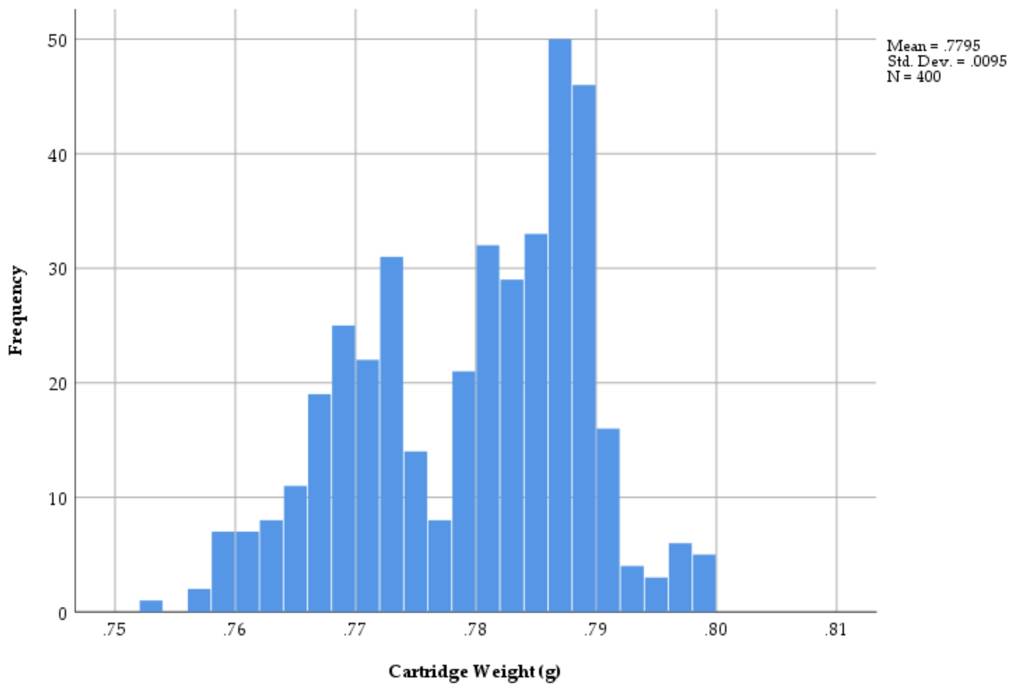

Figure 7. The variation in weight across a sample of 400 brown cap, 1.00 grain cartridges.

3.2. Trial Two—Cartridge Weight (3.00 Grain—Green Cap 0.22″ Calibre)

The cleaned post-firing cartridge weight was subtracted from the full cartridge weight of 97, 3.00 grain cartridges to give the weight of the charge. A histogram of charge weights is shown in Figure 8 which shows two outlying, low values of below 0.24 g with the remaining weights relatively tightly clustered about the mean. The distribution of the weights of the cleaned cartridges is shown in Figure 9, which shows a relatively normal distribution with a range in weights from 0.590 to 0.646.

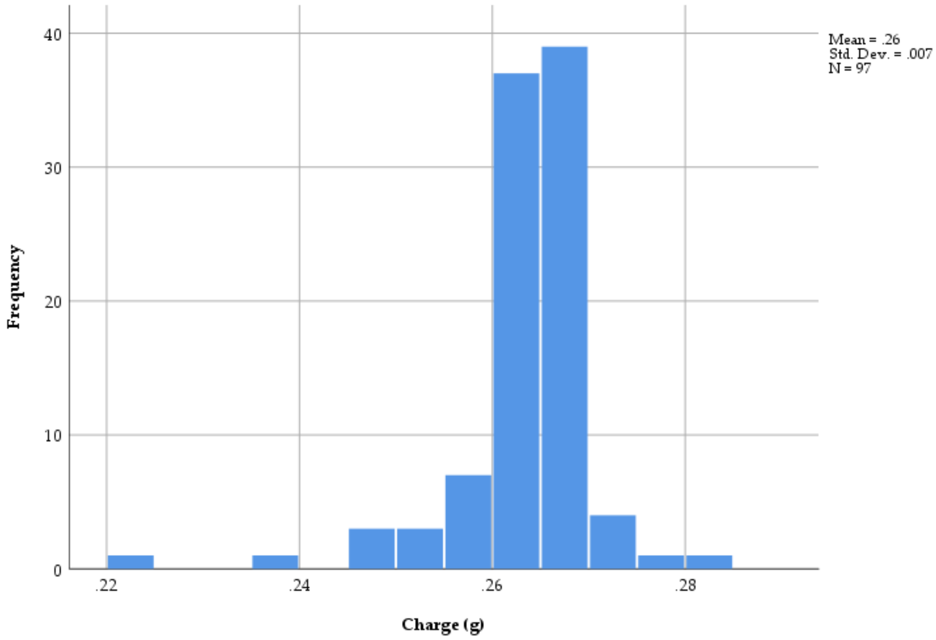

Figure 8. The distribution of charge weights (97 Green 3.00 grain cartridges) (g).

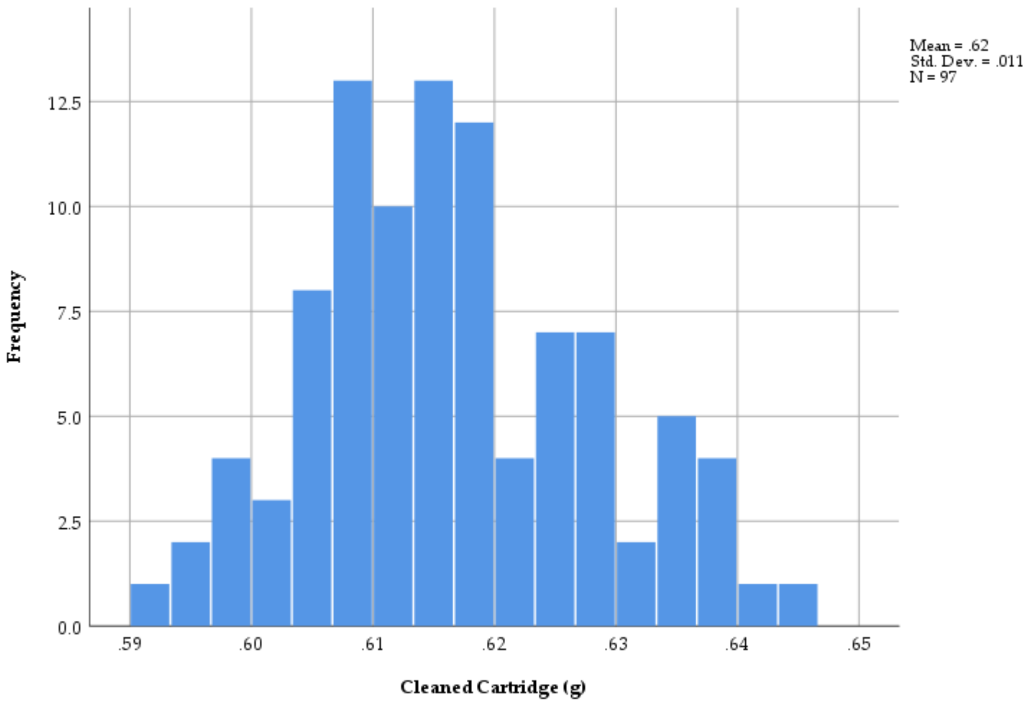

Figure 9. The weight distribution of the cleaned cases (g).

3.3. Trial Three—Velocity Measurement (Velocimeter Method)

The velocities recorded at each measurement position in the initial trial using a 0.25″ calibre Cowpuncher with ten 4.00 grain, three 3.50 grain and three 3.00 grain 0.25″ calibre cartridges are shown in the three figures below. Figures 10–12 show the velocities recorded for each of 10 × 4.00 grain cartridges, 10 × 3.50 grain cartridges and 10 × 3.00 grain cartridges, respectively, at each of the data points in the benchtop velocimeter.

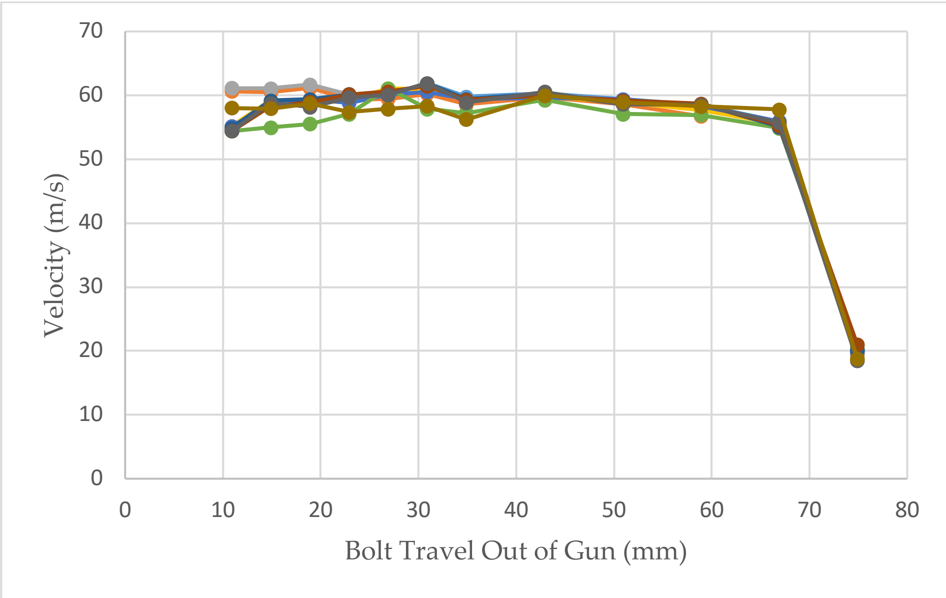

Figure 10. Bolt velocities recorded by the velocimeter at the different measurement points; 10 shots using 4.00 grain cartridges.

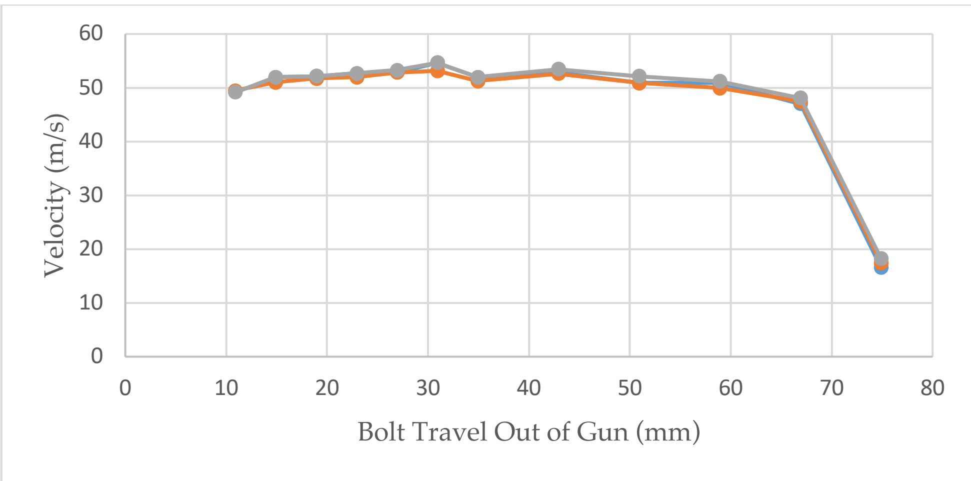

Figure 11. Bolt velocities recorded by the velocimeter at the different measurement points; 3 shots using 3.50 grain cartridges.

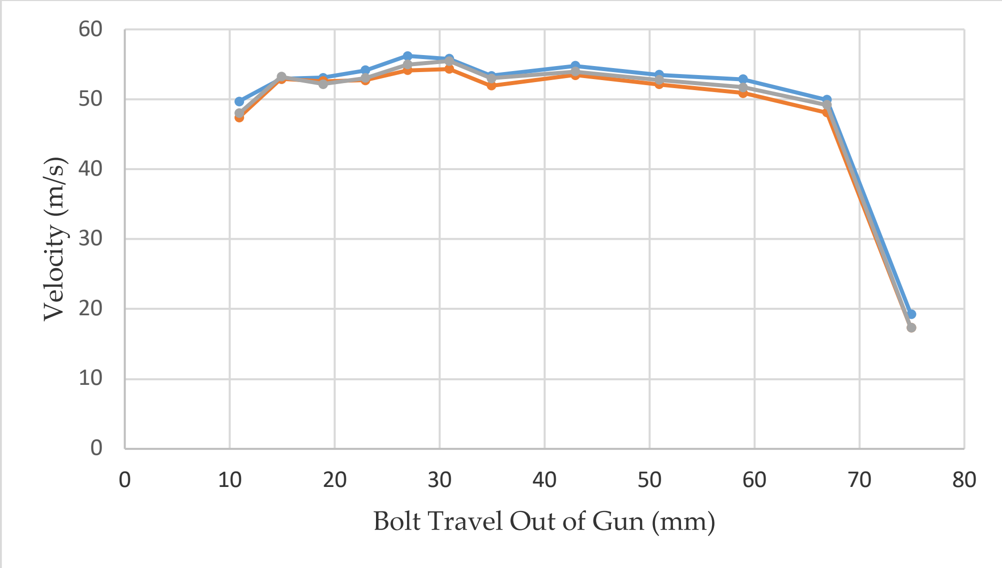

Figure 12. Bolt velocities recorded by the velocimeter at the different measurement points; 3 shots using 3.00 grain cartridges.

Figure 13 shows the scattergram of bolt velocity and propellant fill generated by a random selection of 100 Green 3.00 grain cartridges together with the individual pre-firing cartridge weights (g). Analysis of the data showed that there was a significant ($p < 0.005$) positive linear regression between the cartridge weights and the velocity (Velocity (m/s) = −16.546 + (Grain × 15.764), however, the relationship was weak with an adjusted R square of only 0.08. For the analysis, the extreme grain value of <3.5 and the extreme velocity of <20 m/s were excluded.

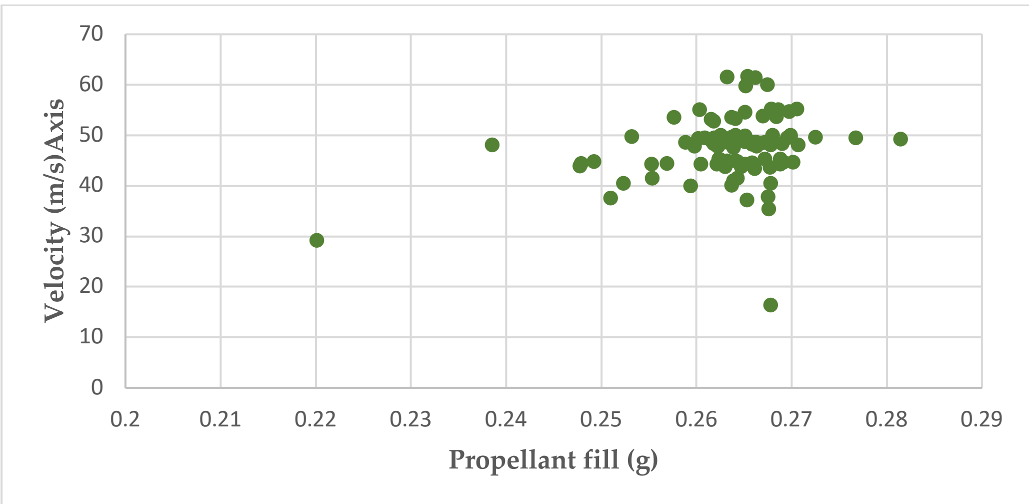

Figure 13. A scattergram of the relationship between propellant fill (g) and velocity (m/s) using 100 Green 3.00 grain cartridges.

3.4. Trial Four—Velocity Measurement Free Flight Method

Figure 14 shows the bolt impact energy levels measured for the three guns (Accles and Shelvoke Small Animal Tool) calculated from the maximum velocity achieved by the bolts. The measurements of the Trials gun were made with the gun cold (round markers in Figure 14) and also after an extended period of use when the gun felt warm in the hand (diamond markers in Figure 14). Figure 14 shows the kinetic energies recorded with 1.00 grain cartridges. The mean energy values for 1.00 grain cartridges with a full set of cold recuperating sleeves were as follows:

Study Gun	47 ± 6 J
Gun 1	41 ± 7 J
Gun 2	32 ± 10 J

The values above exclude all measurements of kinetic energy delivering less than 15 Joules. These data indicate several sources of variation in kinetic energy. Under nominally identical conditions, a significant spread in the energies is observable. This is likely to be due either to variations in the cartridge fill, or to variations in the way the kinetic energy is converted in the gun from shot to shot.

It appeared that a significant proportion of the cartridges (4 out of 41) were faulty (Figure 14), delivering only 4 to 14 J of kinetic energy. While these cartridges did fire, they did not seem to have contained the correct quantity of functioning charge.

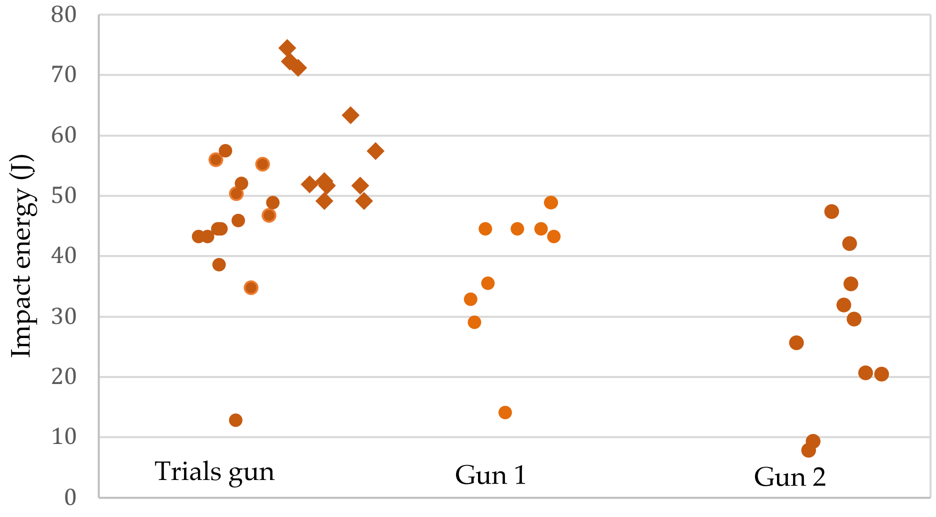

Figure 14. Impact energy for three Accles and Shelvoke Small Animal tools using brown 1.00 grain cartridges. Trial gun energies shown with recuperating sleeves cold (round markers) and warm (diamond markers).

3.5. Trial Five—In Vivo Velocity Measurement

Over the two hundred 'real life' applications measured at the abattoir, the bolt velocity ranged from 35.7 to 62.9 m/s with an average velocity of 50.8 m/s (Figure 15).

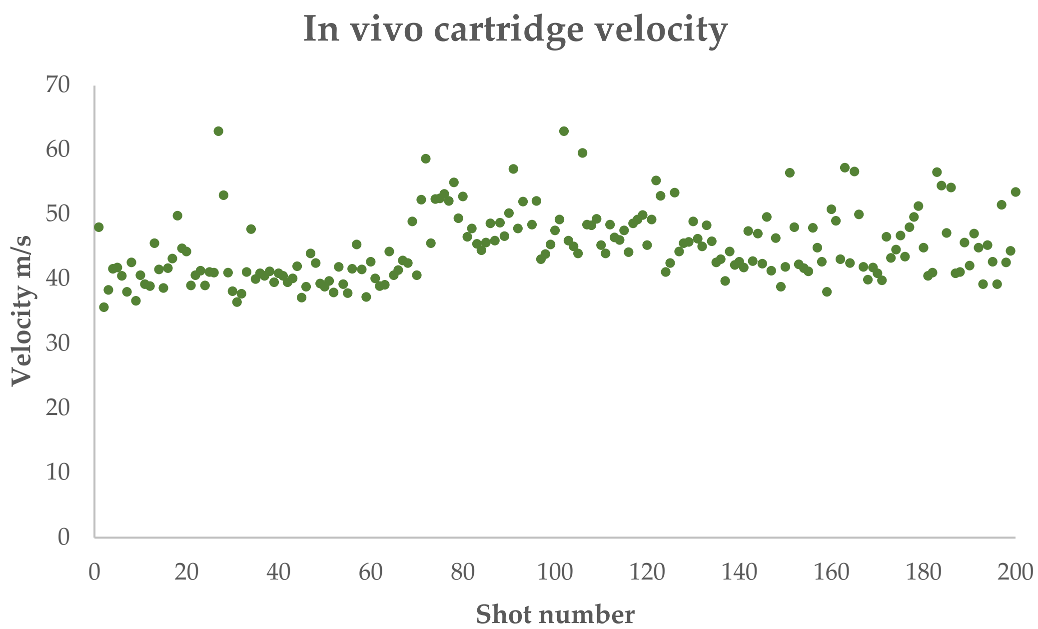

Figure 15. In vivo velocity measurements for 200 cattle shot with green 4.50 grain cartridges in an Accles and Shevoke 'Cowpuncher' penetrating captive bolt device fitted with the experimental velocimeter.

3.6. Trial Six—Cartridge Fill Volume

An example of the cartridge content from a 4.00 and 1.00 grain cartridge is shown in Figure 16, demonstrating the variance in cartridge propellant fill volume encountered between grain loads and that there appeared to be a lack of 'filler' material in the 1 grain cartridges.

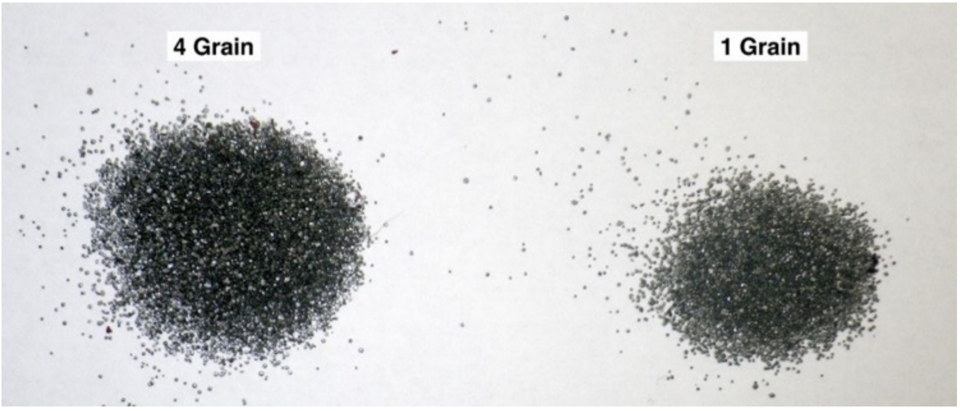

Figure 16. Cartridge contents comparison between a 4.00 grain and a 1.00 grain 0.22" calibre cartridge. Both cartridge cases are the same length and volume.

3.6. Trial Seven—Case Deformity Due to Excessive Headspace

Case deformity was encountered in cartridges post firing from the same device (Figures 17 and 18). The deformities encountered were not correlated in this study to specific firings, as the deformity was noted after Trial 3 had taken place.

Figure 17. Deviation of cases fired in the same device. Right hand case displaying rim end expansion as expected to seal the case within the breech; left hand case showing deformity and signs of having moved backward on firing.

Figure 18. Range of deformities seen in cartridge cases fired using the same device.

4. Discussions

In *Trial One Cartridge Weight (1.00 grain cartridges),* the results demonstrated a bimodal distribution of cartridge weights, which is not the expected results for a product that is meant to be uniform. However, there was an apparent drop in the frequency of cartridges produced at a weight of approximately 0.7750 g with a total range of approximately ±25 mg about this weight. The implications of this distribution with regards effectiveness are unknown; a discussion with the manufacturer would be required to understand how this bimodal pattern had arisen.

4.1. Trial Two—Cartridge Weight before and after Firing (3.00 Grain Cartridges)

It was postulated that the range in cartridge weights could be produced predominantly by variation in casing weights, however, the overall range in casing weights of 50 mg (0.593 to 0.643 g) shown in Figure 9 and in charge of 61 mg (0.220 to 0.281 g) shows that the differences recorded were due, in approximately equal parts, to the variations in both components. As a percentage of mean weight, the variation in charge was considerably larger for fill (±11.6%) than for the case (±4.0%), however, given the equal contribution to overall weight, simply weighing the cartridge did not give an indication of fill.

4.2. Trial Three—Velocity Measurement (Velocimeter Method)

The effect of velocity measurement at different measurement points of the bolt extension shown in Figures 10 to 12 follows very similar patterns with the different cartridges tested. The velocity appears to be fairly consistent between measurement points 11–59 mm of the bolt extension but as expected fall away as the effect of buffer compression slows the bolt before returning it into the breech.

The variation in cartridge weight expressed in grammes in Figure 13 and the resultant bolt velocity shows additional cause for concern. This is because the data indicate that low velocity and hence low energy impact can result from either a cartridge of normal weight or, to one of reduced weight. This would suggest that simply weighing the blank cartridges would not identify all the cartridges that would produce reduced velocity/energy upon firing.

4.3. Trial Four—(1 Grain Cartridges) Free Flight Method

It appears that a significant proportion of the cartridges (4 out of 41) were faulty (Figure 14), delivering only 4 to 14 J of energy. While these cartridges did fire, they seem not to have contained the correct quantity of propellant. These data provide no evidence to suggest that the warming of the buffers is responsible for the bulk of the inter-shot variation. Further investigation would be needed to clarify the situation.

The results from this trial correspond to those of Gibson et al. [15] that demonstrated a wide variation in performance of lower powered cartridges, with 9.76% of the cartridges delivering 4–14 J compared to an expected output of 76 J ± 15% according to the latest data sheet (Frontmatec Accles and Shelvoke).

4.4. Trial Five—In Vivo Velocity Measurement

Daly et al. [11] suggested that 55 m/s should be considered as the minimum velocity to stun cattle with an Accles and Shelvoke Ltd. captive bolt device using Visual Evoked Responses as a conservative indicator of brain dysfunction. As the animal is concussed due to the impact transfer of kinetic energy (E_K) to the cranial vault and E_K = ½ mass × bolt velocity^2, the variance in velocity will have a greater impact on the ability to stun than the mass of the bolt. The average bolt velocity measured in vivo during the 200 applications within an abattoir was 50.8 m/s with a peak of 62.9 m/s, however the lower velocities measured (35.7 m/s minimum) fall below this level; in effect, the lower velocity shot will have three times less energy than the fastest within this batch. The animals were assessed by two experienced researchers (Grist and Wotton) for the effectiveness of the stun using the standard behavioural indicators of loss of posture, no corneal reflex, no pain response and no rhythmic breathing [10,16] and the results corresponded to the findings of von Holleben et al. [21] that the failure to observe the minimum recommended velocity did not correspond to a failure to stun. However, the trial provided evidence of a wide variation in velocity in vivo of the same size cartridges from the same batch fired in the same device. We believe that that the development of the in vivo velocimeter will enable abattoir operatives to be informed of the effectiveness of each shot and for that data to be recorded to give a long-term evaluation of the performance of the gun and monitoring of cartridge batches once the device is in use and velocities can be correlated to stun failure. The results from this development will lead to the production of a practical system that will be made available to the meat industry to either retro-fit to existing guns or, to be incorporated into the design of new models. It is anticipated that the results will be published in an appropriate scientific journal. The benefit to the industry will be to advance animal welfare monitoring during mechanical stunning of all species. This device would enable far greater control over the process and permit Animal Welfare Officers (AWO) to closely monitor the performance of captive bolt guns and cartridge batches and initiate maintenance and/or, replacement before the gun fails. The data produced will also meet current legislative requirements in Europe [22-25].

4.5. Trial Six—Issues Arising from Cartridge Fill Volume

The fact that the lower strength cartridges contain a lower volume of propellant fill than high grain cartridges is likely to vary the performance of the former. As previously discussed, the case size is standard across the different strength cartridges and with lower strength cartridges, the case is not completely filled which affects the loading density (the ratio of the weight of powder charge to the capacity of the case). Issues of low loading density include erratic ignition, change in the pressure curve (moving the peak towards the muzzle), or even overly rapid burning ("detonation") of the powder charge. As with all blank-fired captive bolt devices, the gun is applied with the muzzle pointing down for operation; the lower strength cartridges will allow the propellant to move to the crimped end of the case. This means that there is a greater distance between the priming compound and the propellant, which will affect the ignition and burn rate of the propellant and may lead to propellant burning within the expansion chamber behind the bolt as the latter moves forward. Although all the propellant may burn, it will not burn fast enough to provide the required initial pressure to the captive bolt, resulting in a lower bolt velocity and may affect the ability of the bolt to deliver sufficient kinetic energy to the cranium to stun. Loading density and the effects of reducing this are well known in the shooting fraternity, with self-loaders in competitive shooting being aware that this can affect accuracy by altering the ballistics of the propellant burn [20].

4.6. Trial Seven—Case Deformity

Anecdotally, and having been witnessed by the authors in several abattoirs, there is a practice, with contact firing varieties of captive bolt devices, of using the same barrel cap for both breeches that have to be in position at the stunning point; the back-up device being a preloaded breech which has the same barrel cap fitted for operation. Although barrel caps are not matched to specific barrels, wear of the barrel cap with use may produce a looser fit. Cartridges should be examined after firing for evidence of case deformity due to excessive headspace and the barrel cap corresponding to the breech should be used for secondary stuns. The further development of the in vivo velocimeter will enable more research to be undertaken to establish if there is a link between lower shot velocity and case deformation due to headspace.

4.7. Case Splitting

Recent anecdotal reports from some abattoirs suggest that blank cartridges were occasionally sticking in the breech after firing. It was proposed that this was likely caused by cartridges splitting along their length (Figure 19). The cartridge heads that were stamped E (Eley) did not split, but some of those head stamped AS (Accles and Shelvoke) were found to have split upon removal from the breech. Upon examination, it was found that the new AS cartridges had a more pronounced shoulder that reduced the diameter of the case front by 0.14 mm in both the 0.22″ and 0.25″ calibre cartridges when compared to the corresponding Eley cartridges (Figures 20 and 21). In addition, we noted some evidence of stress lines due to the forming process. These cartridges were not tested in velocity trials.

Figure 19. Case splitting in an AS head stamped 0.22″ calibre cartridge.

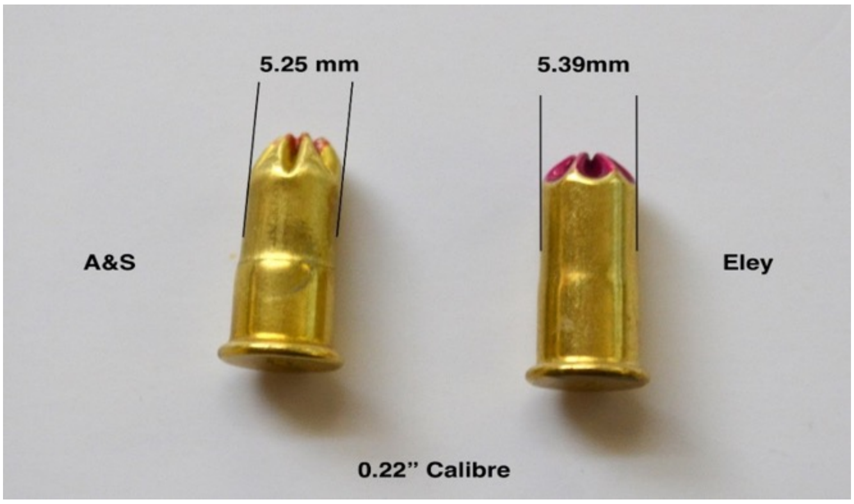

Figure 20. Variation in case diameter between AS and Eley cartridges for use in the same 0.22″ calibre device.

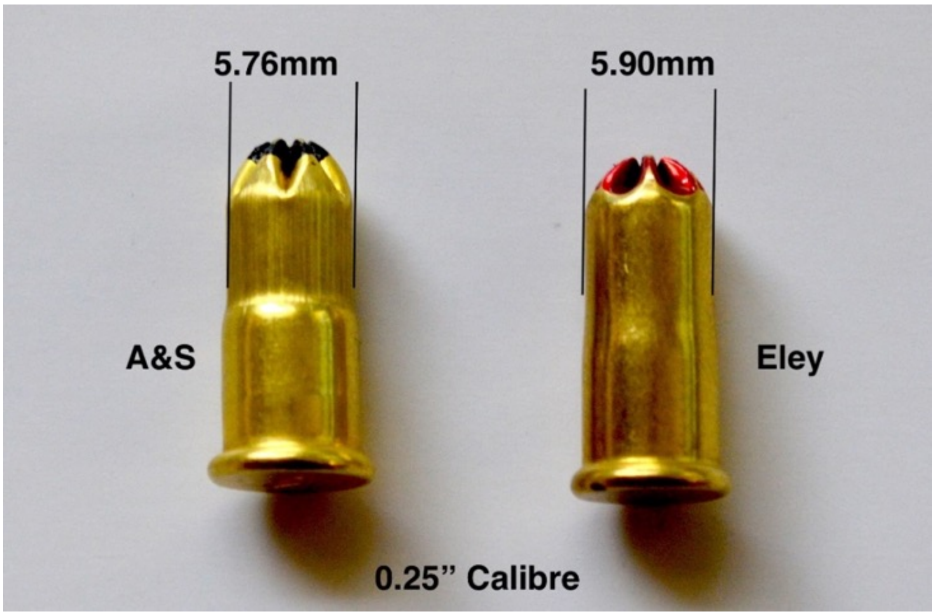

Figure 21. Variation in case diameter between AS and Eley cartridges for use in the same 0.25″ calibre device.

4.8. Variation in Cartridge Performance

This research found that there is a variability in cartridge performance across all ranges, with lower strength cartridges demonstrating more variability in bolt velocity than high grain cartridges. The mean cartridge weight (0.7795 g—Figure 7) represents the standard weight when a 'nominal' target charge of 0.065 g (1.00 grain) of nitrocellulose. The range of 0.7999–0.7537 g (Figure 7) produced a range in weight of 0.0462 g and if the mean cartridge weight (0.7795 g) equates to a fill of 0.065 g nitrocellulose, then 0.7795 − 0.7537 = 0.0258 which would represent 0.0258/0.065 × 100 = 40% reduction in fill.

Given that it is current practice for the same length case to be used for all cartridge strengths and that the variability in the cleaned cartridge case weight was measured as 0.590–0.646 g (Figure 9) for 3.0 grain cartridges, i.e., ±4.5%, this would suggest that the majority of the weight differences were due to differences in the weight of the propellant.

The mean measured charge weight of 0.26 g (range 0.220–0.285—Figure 9) for a 3.00 grain cartridge shows two low outliers, which may explain the variation in velocity shown in Figure 13. This mean measured charge weight (0.26 g) for a 3.00 grain cartridge can be compared to a 'nominal' cartridge fill of 0.195 g (3 × 0.065 g). This difference is difficult to explain.

It is suggested that the result of firing a captive bolt gun with a cartridge that has potentially 40% of the required nitrocellulose may not be audibly detected by the stunning operative but is highly likely to result in an ineffective stun [9]. Abattoirs are required by retailers to record the incidence of double-shots, therefore this occurrence is not only a welfare issue but can also result in punitive action against the slaughter-person.

Physical examination of the cartridges found variability in fill weight, fill volume and case deformity on firing. The question is, is that variability important in the context of the job the cartridges are supposed to be doing? The study of grain against velocity showed that loading does have some weak influence on velocity, however, an R square of 0.08 means it only explains 8 per cent of the variability. Therefore, there are other factors driving the bulk of the variability in velocity. That given, when a cartridge with unusually low grain was used (as seen in Figure 14), even though it is infrequent, it does result in an unacceptably low velocity.

In a situation where the protection of animal welfare by ensuring a stun occurs first time is a paramount concern, the uniform and reliable function of the blank cartridge is an integral part of the process but has been partially overlooked. The future development of the real-time in vivo velocimeter will allow more in-depth investigation into the variables encountered during this investigation, including the role that case deformity due to headspace and this rearward movement of the cartridge may have on bolt velocity and therefore kinetic energy delivered to the animal, the effect of age of cartridge and storage conditions. The in vivo velocimeter will also allow data to be gathered to assess the lower borderline velocity at which the device does not stun, which will allow warnings to be given to the operative in addition to the behavioural indicators they use to assess the stunned state [20].

5. Conclusions

The cartridge is a component and vital part of the stunning process; UK and EU legislation [22–25] emphasise the importance of cartridge strength as a primary parameter for a successful stun and for protecting animal welfare. This investigation, using new cartridges, demonstrated a variability in performance which will only be exacerbated by the environmental and storage conditions within the abattoir setting, including moisture, cartridge age and ambient temperature (as the temperature of the propellant before ignition can have an effect on burn rate) [20]. In Annex 1 of EC1099/2009 on the protection of animals at the time of killing, bolt velocity is listed as a key parameter for penetrative and non-penetrative captive bolt devices [22]. Currently, there is no method of measuring and recording this parameter in vivo. There is available bench testing equipment to measure velocity, such as the Stuncheck (Accles and Shelvoke, Birmingham, UK), but this does not provide information for every shot. It is therefore recommended that the further development of a method of recording every shot in vivo, within a commercial setting, should be encouraged to allow real time recording of velocity.

6. Patents

The Bock Industries Velocimeter will be patented, and as such the setup and methodology is not described in detail in this paper

Author Contributions: A.G. Wrote the paper with assistance from T.G.K., S.B.W., R.B. and J.A.L.; A.G., T.G.K. and S.B.W. analyzed the data from all trials. Trial 1: A.G. and S.B.W. conceived, designed and performed the experiment; Trial 2: A.G., S.B.W. and R.B. conceived and designed the experiment, R.B. performed the experiment; Trial 3: R.B. conceived, designed and performed the experiment, R.B. designed and manufactured the apparatus; Trial 4: J.A.L. conceived, designed and performed the experiments; Trial 5: S.B.W., R.B. and A.G. conceived, designed and performed the experiment, R.B. designed and manufactured the apparatus; Trial 6: A.G. conceived and designed the experiment; Trial 7: A.G. conceived and designed the experiment.

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Chapter Five

GENERAL DISCUSSION

AND

OPTIONS FOR FUTURE RESEARCH

General Discussion

5.1 Research findings

5.1.1 Neonate Euthanasia (Papers One to Five)

This work has provided producers with an alternative to manual euthanasia of neonates and Government bodies with the evidence base to improve animal welfare on farms by recommending the use of mechanical stun/killing. This work provides scientific evidence of the kinetic energy required to ensure an immediate stun/kill in three neonate species (pigs, goats and sheep) and also describes the position the shot must be applied to ensure effectiveness. In the case of neonates, this research also demonstrated that the standard model for kinetic energy transfer does not apply (i.e. differential acceleration of the head and brain) relying on the head resting on a firm surface so that the action of the non-penetrating bolt includes crushing of cranial bone plates into the brain. This will also allow manufacturers of future devices to have a minimum target for kinetic energy generation to ensure a one-shot stun/kill. Since this research has been undertaken, the manufacturers of the small animal tool, Accles and Shelvoke have updated their user manual to reflect the research findings (Appendix 1), however discrepancies exist within this publication, notably the diagram of the shot position for lambs (Fig 5.02 page 9 of instruction booklet, Accles and Shelvoke, 2018 Annex 1) and their recommendation to use a 1 grain cartridge for this species, despite the research findings in Paper Five recommending a different shot position and minimum of 1.25 grain be used to ensure an effective kill.

By comparing the subjective behavioural characteristics observed to an objective measure of brain activity, this work also allows training material to be produced for farm personnel both to recognise the effectiveness of the shot, in terms of behavioural indicators of brain death, and also to alleviate concerns they may have over post shot physical activity in a brain-dead animal. This training material is in production and will be published as a training video for producers in the near future.

5.1.2 Captive Bolt (Papers Six and Seven)

This work will provide abattoirs and government enforcement agencies with further training material and tools that can be used as part of the investigation into the causes of miss-stuns and repeated stun attempts by increasing understanding of the mechanical stunning procedure.

The work on macroscopic brain assessment of multiple shot bovines does suggest the 'one size fits all' approach to shot position, recommended to be at the intersection of two imaginary lines between the top of the eyes and the base of the opposite horn bud, may need to be adjusted depending on the age, sex and breed of the animal to be stunned, but a larger dataset would be required to make proposed changes that would be statistically relevant. This current work has provided detailed photographs and reports that government officials and participating abattoirs are using to train slaughter personnel on positioning of shots.

The examination and demonstration of variability of the cartridges that are used as the main propellant source for captive bolt devices on-farm and within abattoirs in the European Union does raise concerns. The variation found in velocity and hence kinetic energy produced within a batch of cartridges could be the difference between a successful and unsuccessful stun/kill, especially with the lower powered cartridges that are used for euthanasia of poultry and neonate lamb, kids and piglets on farm.

5.2 Future Options for research

5.2.1 Neonate Euthanasia

Following identification of the minimum kinetic energies and the recommended shot positions for piglets, lambs and kids, there is the possibility of developing new mechanical methods to ensure immediate and reproducible euthanasia of neonates on-farm. The main obstacle for uptake of the mechanical method by producers after the initial financial outlay for the devices, is the cost of the propellant source. The Bock Industries Zephyr EXL requires either an air compressor capable of delivering 120psi or a CO_2 canister; the Accles and Shelvoke Small Animal Tool requires cartridges that cost approximately 10 pence each. One avenue that could be explored is the development of an alternative power source for such devices, such as spring or rubber with no follow-on costs, although these are unlikely to be able to provide sufficient kinetic energy without the design of a cam-lever cocking system. Development of such equipment would require devices that are sufficiently robust to withstand 'agricultural' neglect.

Following the adoption of mechanical systems by producers, as a method of euthanasia there will be a potential 'one health' link to human paediatric traumatic brain injury research cases. This could be achieved through using neonates as a model species (Finnie et al 1998; Wagner 2012) as recorded velocities or kinetic energies and impact areas will be known.

Research involving the postmortem examination of neonate cadavers that have been euthanased due to disease or ill thrift may lead to a better understanding of the issues, post parturition, in various production methods and lead to possible management changes that will improve animal welfare and increase profitability.

There is potential for research into the ancillary brain lesions, such as porencephaly and abscesses that were encountered during the research, to assess their frequency and their possible effect on these animals. For example, are some of the neonates euthanased because of the symptoms produced by these lesions, or are they simply a coincidental finding?

It would also be interesting to study agonal breathing in more detail using the animal model to explain a similar effect in brain dead humans with a patent heartbeat, including the “Lazarus” effect.

5.2.2 Captive bolt

I am interested in conducting further research on terminal ballistics with captive bolt use and mechanisms of their effect on neural pathways including: 1. the effect of direct contact of the bolt with the head of the animal. 2. indirect contact phenomena and the roles of hydraulic and hydrostatic shock as it is known for example that the pig brain is approximately 73% water (*Wagner et al 1996*), therefore it should behave as a fluid mass propagating pressure waves, and 3. if the concave bolt head design propels an air bubble into the brain, in addition to the plug of bone it cuts out on impact. For example, Atkinson et al (2013) describe a situation where, following repeated stun attempts an examination of the penetrating captive bolt revealed damage to the outer rim edge at the tip of the penetrating bolt. Once this was rectified the number of restuns reduced from 19% to 3%. This raises several possibilities in terms of terminal ballistics – does the concave bolt tip retain an air bubble when impacting the head which can be dissipated on impact if the rim is incomplete? Or does the incomplete cutting edge reduce kinetic energy on impact by snapping cranial bone rather than cutting it?

The effect of bolt head design and the effect of heat generation during penetration through the skull and the brain deserves further research. Although research is leading to a better understanding of the effects of the application of a captive bolt on the brain function in animals, I believe there would be an advantage to link the mechanics involved with biomechanics to enable researchers to gain a better understanding of the process of mechanical stunning and concussion.

The development of the Velocimeter in association with Bock Industries will allow further research to be undertaken on the role of velocity and stunning, with larger plants being able to provide large data sets which can be matched against miss-stuns, cartridge deformity and other aspects found during the writing of Paper Seven.

Further research should be conducted on brain position in older and continental breeds of cattle as Paper Six (Macroscopic examination of bovine heads) produced a small dataset but did suggest that with some animals a higher recommended shot position may be required to ensure penetration of the midbrain area to prevent recovery after an effective stun.

5.3 Conclusions

5.3.1 Mechanical Euthanasia of Neonates

The research on mechanical euthanasia of neonate piglets, kids and lamb has provided producers worldwide with two products as an alternative method of euthanasia to manual blunt force trauma or hypercapnia. The single application stun/kill devices investigated would remove the uncertainty of manual blunt force trauma, are easy to apply with minimal training required and the results are reproducible. In cases of mass euthanasia for the purposes of disease control, these mechanical devices are not dependent on the physical ability of the operator.

5.3.1a Piglet Neonate Euthanasia

The Bock Industries Zephyr EXL non-penetrating captive bolt device provides for a single application stun/kill method for neonate piglets up to 10.9Kg liveweight when powered by 110psi airline (delivering a kinetic energy of 27 joules) and applied on the parietal bone. This device has been demonstrated to abolish visual evoked potentials in the laboratory and field trials of the device validated these findings using behavioural indicators of loss of brain function (Grist *et al.,* 2017, 2018a).

The Accles and Shelvoke Small Animal Tool (formally the Cash Poultry Killer (CPK200)) provides for a single application stun/kill method for neonate piglets up to 5Kg liveweight when powered by a one grain 0.22” calibre cartridge (delivering a kinetic energy of 47 joules) and applied on the parietal bone. (Grist *et al.,* 2018b)

5.3.1b Goat Neonate Euthanasia

The Accles and Shelvoke Small Animal Tool (formally the Cash Poultry Killer (CPK200)) provides for a single application stun/kill method for neonate goats up to 5Kg liveweight when powered by a one grain 0.22” calibre cartridge (delivering a kinetic energy of 47 joules) and applied at a specific shot position (on the midline, between the ears with the chin tucked into the neck) (Grist *et al.,* 2018c)

5.3.1c Lamb Neonate Euthanasia

The Accles and Shelvoke Small Animal Tool (formally the Cash Poultry Killer (CPK200)) provides for a single application stun/kill method for neonate lamb up to 5Kg liveweight when powered by a 1.25 grain 0.22” calibre cartridge (delivering a kinetic energy of 107 joules) and applied at a specific shot position (on the midline, between the ears with the chin tucked into the neck) (Grist *et al.,* 2018d). Following this research, the manufacturer of the Small Animal Tool is reproofing the device to allow for a 1.25 grain cartridge to be used with this gun. (Joe Holland, Accles and Shelvoke, Personal communication)

5.3.1d General Discussion of conclusions

This research validated two on-market devices for the euthanasia of neonates and found that one required more power than the manufacturer’s recommendation to stun/kill. This highlights an issue with stunning equipment both in Europe and Worldwide that, although parameters are listed (EC1099/2009, EFSA 2013), the European legislation tends toward statements such as ‘in accordance with manufacturers recommendations’ but does not provide for independent validation of the equipment. Consideration be given to setting up an independent research led group which provides assurance that any device used for stunning or killing of animals either sold for on-farm, small producer or on a commercial scale, mechanical, electrical, controlled atmosphere or other method, actually performs as required. This is alluded to in the European legislation (EC1099/2009 Article 20 Paragraph 1.) "*Each Member State shall ensure that sufficient independent scientific support is available to assist the competent authorities, upon their request, by providing: b) scientific opinions on the instructions provided by manufacturers on the use and maintenance of restraining and stunning equipment".* Rather than relying on the request of the competent authorities, would the development of a welfare standard or 'kitemark' for such equipment improve animal welfare and provide users with confidence in the equipment and methods they are using?

5.3.2 Captive Bolt Stunning of Cattle

5.3.2.a Macroscopic examination of bovine heads

This initial trial provides a method of head examination that could be carried out by the Animal Welfare Officer and regulators as part of an investigation of failures of a mechanical stunning system and to provide training material for slaughter staff tasked with assessing for effective stunning in cattle. (Grist *et al.,* 2019a).

5.3.2.b Examination of cartridge performance

This research demonstrated that there exists an inherent variability in the cartridges used as a power source for captive bolt pistols, and as such, could lead to welfare issues such as animals needing a second or further application of the device to ensure a stunned state prior to exsanguination (Grist *et al.,* 2019b).

5.3.2.c Discussion of the conclusions

The work covering cartridge variability and macroscopic examination of bovine heads highlights that the need for secondary or tertiary stun applications are not always the fault of the slaughter personnel and care needs to be taken in assessing the root cause of the failure. In addition, following the European legislation requirements there should be a review of the method in cases of failure of the stunning system (EC1099/2009 Article 2(f) "*in order to identify the causes of any shortcomings and the necessary changes to be made to those operations"*).

Increasing the number of bovine heads examined and relating the sectioned heads to breed, age and sex will build up a database of anatomical variation within breeds that will inform the recommended shot position based on those factors, rather than a generic recommended position, to reduce the number of animals requiring secondary shots.

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Annex 1
Accles and Shelvoke Small Animal Tool Instruction Manual

FRONTMATEC
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CASH® Small Animal Tool

User manual

DO NOT ATTEMPT TO USE THESE STUNNING TOOLS UNTIL YOU HAVE READ AND UNDERSTOOD THE USER MANUAL

FRONTMATEC accles & SHELVOKE

DISCLAIMER

This instruction manual is correct at the time of printing. However, because our policy is one of constant development and improvement, details and images may vary slightly from those provided in this publication.

ONLY EVER USE GENUINE ACCLES & SHELVOKE REPLACEMENT PARTS. NOT USING GENUINE PARTS MAY LEAD TO PREMATURE COMPONENT AND TOOL FAILURE, WHICH COULD ENDANGER THE OPERATOR AND THOSE IN THE IMMEDIATE VICINITY. IT WILL ALSO INVALIDATE OUR ORIGINAL EQUIPMENT WARRANTY.

ACCLES & SHELVOKE WILL ACCEPT NO LIABILITY IF ANY COMPONENTS OTHER THAN THOSE SUPPLIED BY ACCLES & SHELVOKE ARE USED WITH OUR ORIGINAL EQUIPMENT. THE RESULTANT LIABILITY WILL BE WITH THE END USER OR THE DISTRIBUTOR WHO SUPPLIED THE UNAPPROVED REPLACEMENT PARTS.

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accles & SHELVOKE

The **CASH**® Small Animal Tool is a cartridge powered, trigger operated, concussive, cylindrical style tool with automatic bolt return. It is available in .22" calibre and is designed for use on small animals such as piglets, kids, lambs and poultry. These tools are intended for professional use.

Product	Product code	Product description	Calibre	Maximum permitted cartridge
CASH® Small Animal Tool	CPK200	**CASH**® Small Animal Tool	0.22	1 grain (.22 BROWN)

The **CASH**® Small Animal Tool is a captive bolt device which kills the target animal by means of a blow to the head (and brain). These tools are designed to kill all designated animals in accordance with EU Council Regulation (EC) number 1099/2009 On the Protection of Animals at the Time of Killing.

The **CASH**® Small Animal Tool has been on the market for many years, and in that time has earned a reputation for being a reliable and effective tool.

To ensure the safety of the operator, and quality of products, all Accles & Shelvoke tools are proof tested in accordance with the Rules of Proof 2006. We have several 'assistant proof masters' who are accredited by the British Proof House (formerly the Birmingham Proof House, www.gunproof .com). We work to standards set by the Commission Internationale Permanente pour l'Epreuve des Armes á Feu Portatives (CIP). All tools are "Proofed" prior to being released to customers. Proofed components are stamped with the mark of the British Proof House, so that users can be assured of the quality and safety of the product.

The tool has been designed to be easy to use by implementing a palm/finger trigger.

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Attribute	Stunner model number
	CPK200
Length (mm)	315
Width (mm) at widest point	50
Weight (kg)*	1.5
"A" weighted Sound Pressure Level at work station (dB)	83
"A" weighted Sound Power level (dB)	77
"C" weighted peak emission (dB)	119
Calibre	.22
Chamber	Straight

*Rounded to 1 decimal place

Sound values determined according to EN 15895 using EN ISO 3744, using the maximum rated cartridge for a given tool. Tests conducted using simulated load (paper sheets and plasticine).

The A-weighted sound pressure level and A-weighted sound power level have been calculated - and are hence valid – at the maximum number of driving processes in one second.

The maximum number of driving processes in the **CASH**® Small Animal Tool is one per second.
This applies to all of the tools in the range included in this manual.

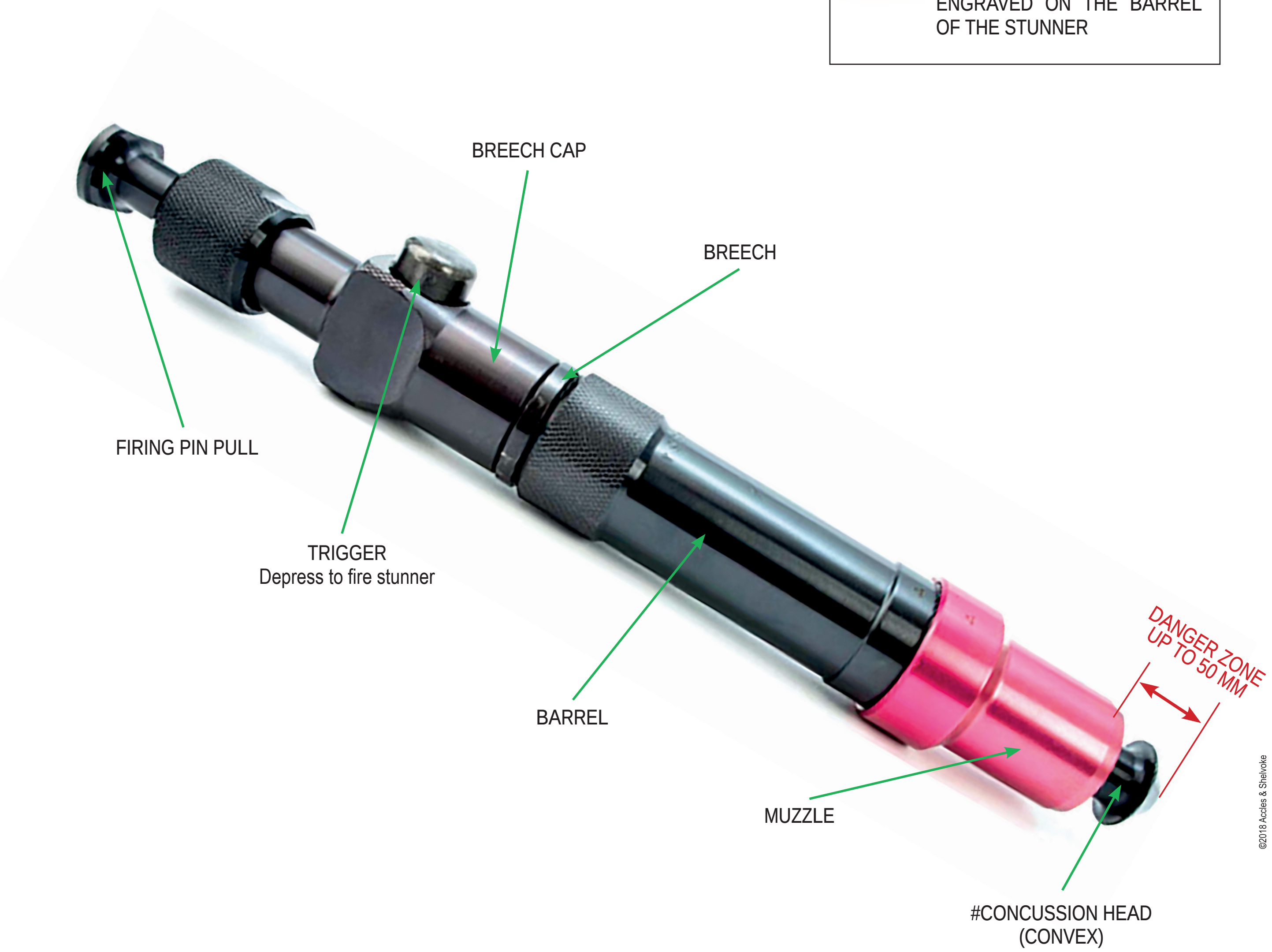
Information about vibrations

EN15895 states - for cartridge operated hand tools, the vibration total value to which the hand-arm system is subjected does not exceed 2.5m/s². The generated mechanical recoil that is transmitted into the hand and arm of the operator is not considered to be a vibration.

CASH® Small Animal Tool

FIG. 3.01

THE MAXIMUM GRAINS (GRN) AND SERIAL NUMBER OF THE TOOL CAN BE FOUND ENGRAVED ON THE BARREL OF THE STUNNER



NOTE - every tool in the **CASH**® range is stamped with the maximum permitted (PROOF) cartridge, showing the maximum grains (GRN) that should be used.

NEVER USE A MORE POWERFUL CARTRIDGE THAN THE MAXIMUM PERMITTED CARTRIDGE AS STAMPED ON YOUR STUNNING TOOL

NEVER POINT THE MUZZLE END OF THE STUNNING TOOL AT YOURSELF OR ANY OTHER PERSON

#NOTE
CASH® Small Animal Tool is supplied with 2 concussion heads:
- Convex head for large poultry and quadrupeds
- Flat head for small poultry

This section provides a guide to the correct stunning position and direction for certain animals, and helps you to select the correct cartridge for that animal.

The cartridge selection information provided within this section of this instruction manual is not categorical and is hence supplied as guidance only.

GOOD PRACTICE

- Understand animal welfare - refer to section 4 for further guidance
- Always ensure your stunning tool is in good working order
- Stunning tools should be cleaned and maintained in accordance with the instructions within this manual
- Ensure at least 2 stunning tools are present near the stunning box
- Stunning tools wil require more maintenance if used with cartridges that are more powerful than is necessary for the target animal
- It is recommended that the stunning tool is validated for manufactures performance each day before carrying out stunning

EFFECTIVE KILLING

The blow being applied to the correct part of the skull and in the right direction is important in ensuring an effective kill shot. The tool will crush the skull and the operator can be assured that death will follow. Refer to the diagrams and selection charts within this section for guidance. To obtain maximum effect, the muzzle of the **CASH**® Small Animal Tool must always be held firmly against the head.

The physical signs of an effective kill are:

Quadrupeds

- Animal collapses
- No rhythmic breathing
- Fixed, glazed expression in the eyes
- No corneal reflex
- Relaxed jaws
- Tongue hanging loose

Poultry

- Uncontrolled, severe wing flapping
- No rhythmic breathing immediately after stun
- No control over neck movement
- Leg flexion and extension
- Fixed, glazed expression in the eyes

FAILURE TO KILL

If the target animal is not killed after the shot is applied, it should be immediately killed by an alternative method.

CORRECT STUNNING POSITION
PIGLETS

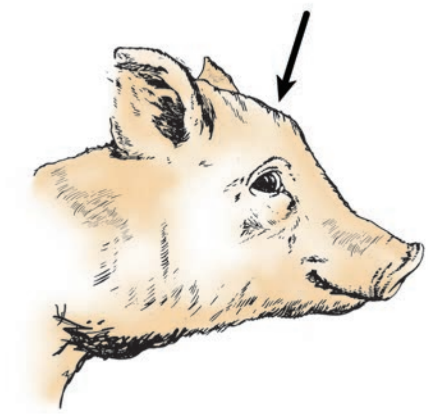


FIG. 5.01

NOTE - align tool as indicated by the black arrow centrally on the target animal's head.

	.22" range CASH® Small Animal Tool (CPK200)
For piglets	Brown
For weaners and growers	Brown
For market pigs	N/S
For very heavy animals	N/S
For heavy sows and boars	N/S

N/S: Not Suitable for denoted animal size

CORRECT STUNNING POSITION
LAMBS/KIDS

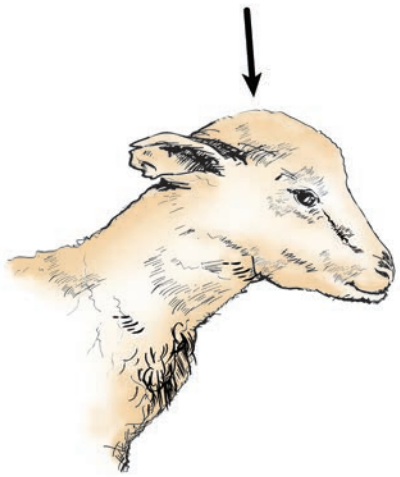


FIG. 5.02

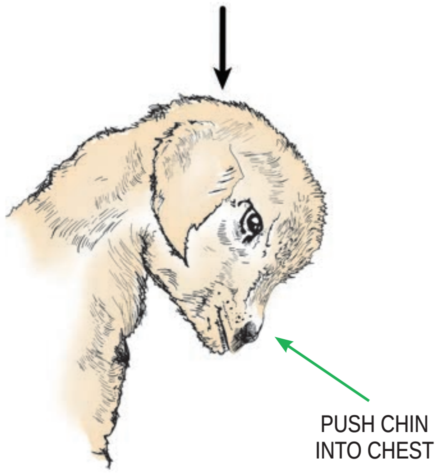


FIG. 5.03

NOTE - align tool as indicated by the black arrow centrally on the target animal's head.

	.22" range **CASH**® Small Animal Tool (CPK200) 
For lambs and kids	Brown
For ewes	N/S
For rams	N/S
For goats	N/S

N/S: Not Suitable for denoted animal size

OTHER ANIMAL SPECIES

Although the **CASH**® Small Animal Tool is predominantly used for the killing of poultry, lambs and piglets we know from our 100 year history that they are also used for other animal species:

As conclusive test results are not available for these animals, we recommend you seek the advice of an independent expert to understand the appropriate head placement and tool direction, prior to killing.

ACCLES & SHELVOKE CARTRIDGE RANGE

The tables on the next pages identify which cartridges from our range are suitable for use with a given tool from the **CASH**® Special range of products. The cartridges are supplied in quantities of 50 in a metal tin, or 1000 in a box. All of our products will be clearly branded as Accles & Shelvoke **CASH**® cartridges.

It is a condition of Accles & Shelvoke's product liability insurance that only **CASH**® cartridges, in **CASH**® cartons and bearing "E" or "C" headmarks, be used in stunners manufactured by Accles & Shelvoke. It follows therefore, that no liability whatsoever can be accepted for any claim, including injury, should any other brand of cartridge be used.

Where cartridges other than these are used, Accles & Shelvoke will not accept responsibility for:

- The safety of the operator
- The humaneness of the stun
- The correct operation of the stunning tool
- The premature failure of parts

Cartridges must be stored in cool, dry conditions. Exposure to excessive amounts of moisture may affect cartridge performance, which in turn will affect tool performance with the potential to create an ineffective stun of the animal.

When not in use, cartridges should be locked away separately from any stunning tools.

NOTE - "N/S" - with reference to the compatability tables in this section of the manual, "N/S" identifies that the cartridges highlighted are not suitable for use in the stated **CASH**® product in the table.

EXCEEDING THE PERMITTED STRENGTH OF CARTRIDGE COULD BE HAZARDOUS TO THE OPERATOR, WILL REDUCE THE EXPECTED LIFE OF THE TOOL OR ITS COMPONENTS AND WILL INVALIDATE OUR WARRANTY

STUNNING TOOL AND CARTRIDGE COMPATABILITY - .22" CALIBRE

		Grain	1	1.25	2.5	3	4	4.5
Calibre	Product code	Description	Brown	Pink	Purple	Green	Red	Black
0.22"	CPK200	**CASH**® Small Animal Tool	YES	N/S				

PART NUMBERS FOR .22" CARTRIDGES BY QUANTITY

To order your .22" calibre cartridges, please select the appropriate part number from the table below:

Size/Grain	Colour	50 in a tin	1000 in a box
1	Brown	7505T	7505

KEY PARAMETERS FOR CARTRIDGE SELECTION

The table on this page details the key performance parameters for the **CASH**® Small Animal Tool when used in conjunction with approved Accles & Shelvoke cartridges.

This information is issued to satisfy the requirements of EU Council Regulation (EC) number 1099/2009 On the Protection of Animals at the Time of Killing. It provides guidelines to aid the selection of an appropriate cartridge to perform effective killing on a particular type and size of animal. Whilst we believe this regulation is open to interpretation, these parameters have been published following years of experience.

These figures may only be used when quoted with the associated notes. Accles & Shelvoke will not accept responsibility for the reliability of these figures if used out of context.

Product code	Calibre	Cartridge grains (nominal)	Frontmatec Accles & Shelvoke cartridge colour	#Bolt (head) diameter (mm)	Average bolt velocity* (m/s)	Minimum bolt exit length** (mm)	Energy generated (J)
CPK200	.22"	1	Brown	10.7/25.0	24.6	Up to 50 mm	53.7

NOTES

- # Bolt shank and head diameters quoted
- * When measured in air over a distance of 8 mm
- ** When fired in air

These quoted figures have been established during extensive testing at the Accles & Shelvoke factory test facility.
At the time of going to print, the current Accles & Shelvoke stun check unit is not suitable for the velocity testing of the **CASH**® Small Animal Tool.
The velocity figures quotd are accurate within +/- 10%, when using a stunning tool that is in good condition and maintained in accordance with this manual.