AMPC

AUSTRALIAN MEAT PROCESSOR CORPORATION

FINAL REPORT - Review of Percussive Stunning

Project code:	2016.1040
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Date Submitted:	30 June 2016
Date Published:	1 September 2016
Published by:	AMPC

The Australian Meat Processor Corporation acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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1.0 Milestone Description

MILESTONE	ACHIEVEMENT CRITERIA
1	• Collate and analyse stunning data (penetrative captive bolt and non-penetrating percussive stunning) • Collate, review and summarise the research that has been completed to-date using the information from previous literature review completed during the review of the AW standard. This will include any updates as necessary • Milestone report submitted to and approved by AMPC
2	• Final report and Snapshot submitted to and approved by AMPC.

Table 1 Milestone description

2.0 Abstract

Non-penetrating percussive stunning is used widely in Australian abattoirs and when correctly executed, it induces a state of concussion during which the animal is unconscious. However, in the EU, non-penetrating percussive methods are not permitted for stunning livestock, with the exception of small ruminants (<10kg). The change to the EU regulation was based primarily on an EFSA report (2004), which cited a field study carried out in two cattle abattoirs in Germany and showed that non-penetrating stunning had a high failure rate under commercial conditions. In Australia the conditions under which non-penetrating stunning is used are generally different to those observed in the EU field surveys. There is likely to be better restraint, with most plants using controlled head restraint and the equipment consists of high velocity pneumatic stunners, that have a lower incidence of mechanical failure than cartridge-powered tools. Furthermore, all export abattoirs monitor the stunning process and collect data (KPIs) to demonstrate that they can meet the requirements for effective stunning, as required by the industry standard (and customer requirements). This project involves analysis and publishing of data to support the use of percussive stunning as an acceptable stunning method under Australian conditions. This final report is a summary of the published scientific data and industry findings to establish the type of issues that have been encountered overseas. This will be used to determine optimum stunning conditions for the use of non-penetrating methods in Australian establishments, for submission to a relevant scientific journal (once the final report has been approved).

3.0 Project Objectives

OBJECTIVES	DESCRIPTION
1	• Determine the acceptability of percussive stunning as a stunning method under Australian conditions
2	• Review published scientific data and industry findings to establish what issues have been encountered overseas and determine optimum stunning conditions for adaptation in Australia

Table 2 Project objectives

3.1 Determine the acceptability of percussive stunning as a stunning method under Australian conditions

- Review the current use of percussive stunning in Australia and provide information on the variables between abattoirs (For example, stock handling prior to slaughter, restraint, head restraint, stunning device type/power, maintenance, stun to stick interval and sticking method)
- Analyse the KPIs from the plants that use percussive stunning
- Identify correlations (stun effectiveness, stun stick interval, insensibility on the bleed rail) and compare with other acceptable stunning method outcomes (e.g. captive bolt)

3.2 Review published scientific data and industry findings to establish what issues have been encountered overseas and determine optimum stunning conditions for adaptation in Australia

- Collate, review and summarise the research that has been completed to-date (already completed in-part during the review of the industry standards (AW1).
- Develop a draft article for publication that supports the continued use of percussive stunning in Australia.
- Submit for publication in relevant journals.

4.0 Methodology

Consultation with AUS-MEAT Limited and identified industry representatives was carried out in order to establish the key technical issues affecting the use of non-penetrating percussive stunning in Australia. Analysis of audit information was used to set the context against which a stock-take and review of published literature on non-penetrating percussive stunning was carried out (Appendix 1 - 8.1). The review also identified knowledge gaps and any areas that are not supported by scientific research to enable recommendations for future animal welfare R&D to be completed in this area (Section 7.0). Although not part of the initial projective objective, an industry survey was completed (Appendix 3 – Section 8.3).

The project TOR used the term 'Percussive stunning' to describe non-penetrating percussive stunning. This term shall be used interchangeably with non-penetrating stunning throughout this report and within any subsequent associated documentation.

4.1 Industry performance

The industry standard (to address animal welfare compliance) was developed by AMIC through AMPC. It is pitched at a higher compliance standard than the regulatory requirements. Implementation of the standard is voluntary, but it is gaining ever expanding acceptance. Verification of compliance involves the use monitoring activities and the routine collection of KPI data. Unless customer specifications require a more stringent different assessment process, the audit sample is determined using the guidance in the AMI Recommended audit and animal handling guidelines 2012, where the number of animals assessed equates to 10% of the hourly production.

For mechanical stunning (penetrating captive bolt and non-penetrating percussive stunning), the KPIs, detailed in the industry standard, relate to:

- Production of a successful stun with the first shot (95% stunned with the first shot);
- Stun to stick interval (<30s - where non-penetrating percussive stunning is used); and
- Subsequent insensibility on the bleed rail (100% of animals insensible).

Independent third party auditors (AUS-MEAT Limited) verify effective stunning during scheduled on-plant audits. They have found that industry (certified plants) can meet this standard (the above KPIs) when using penetrating or non-penetrating stunning equipment. At the time of writing there were 42 abattoirs that are certified for the processing of cattle. Audit data from the most current external audit for each plant was reviewed, with initial results presented in Section 6.1. Analysis was limited to a preliminary determination of difference between effectiveness when different stunning methods are used. Unfortunately, a more detailed analysis of plant specific conditions and their impact on stunning efficacy was not possible due to the type and detail of data collated from external audit reports. This is discussed further in Section 5 – Project summary and overall progress report.

4.2 Literature search

A search of published scientific and technical literature was carried out using Web of Science (Thomson Reuters, New York). Combinations of the keywords listed in Table 3 were used. References were collated in an Endnote® Database (Thomson Reuters, New York). Relevant articles were those which described the method of stun, its efficacy, or factors contributing to efficacy, in cattle. Non-scientific literature and media sources were not accessed during the course of the search. Religious or cultural concerns are not within the scope of the review and were not studied.

KEY WORD	REFINEMENTS
Stun	Non-penetrative (non-penetrating), mechanical, captive bolt, percussive, knocker, humane, mushroom, penetrating
Livestock	Cattle, bovine, animal
Welfare	Abattoir, slaughterhouse, stunning, slaughter, assessment, audit

Table 3 Literature search criteria

5.0 Project summary and overall progress

The project has been completed against a revised timescale and within budget. One objective of milestone 1 was to correlate industry information on effective stunning with the use of head restraint and use of particular stunning equipment etc. It was anticipated at the outset that specific process information related to stunning would be available through audit data, however upon review, it was found that the external audits do not routinely collate this type of information. The author contacted certified beef plants (through AUS-MEAT) to collect this information (through an on-line survey approved by – Appendix 3). The information from the survey is still being collected and analysed. It is anticipated that this information will provide additional evidence to support the conclusions and recommendations detailed in this report. This additional activity has required a revised timescale, though has not increased the project project. The draft article for publication will be submitted for review after the approval of this final report and when all additional industry data acquired through the survey process has been considered.

6.0 Discussion

6.1 Industry performance

The external audits performed in 2014/2015 covered 42 certified cattle facilities (with a total throughput of 29,134 cattle per shift). A total of 3,235 cattle (across the 42 facilities) were assessed during the audit process. The total number assessed per facility being dependent on the throughput of each shift (see Section 4.1).

EFFECTIVE STUN TYPE CROSS TABULATION							
			Stun type			Total	Exact sig - Pearson Chi-square
			PCB	NP	E		
Stun	Effective	Count	670	2349	123	3142	
		% within stun type	99.6%	96.4%	98.4%	97.1%	<0.001
	Ineffective	Count	3	88	2	93	
		% within stun type	0.4%	3.6%	1.6%	2.9%	<0.001
Total		Count	673	2437	125	3235	

Table 4 Comparison of stunning efficacy in certified abattoirs when using different stunning methods

Table 4 is a summary of the effectiveness of different stunning methods (penetrative captive bolt, non-penetrating percussive device and electrical stunning). Out of a total of 2437 animals assessed for efficacy of non-penetrating percussive stunning, 2349 animals were effectively stunned with the first shot (96.4%). This means that 3.6% (88 animals) of the first shots using a non-penetrative stunning were assessed as ineffective. In commercial slaughter, it should be possible to ensure effective stunning in almost 100% of the animals (Grandin, 1998). In the AMI recommendations (developed by Temple Grandin - AMI Foundation (2012)), which is the basis of many North American retailer standards (for example, McDonalds), stunning efficacy scores in excess of 95% are deemed acceptable, with 99% referred to as 'excellent'. Using this criteria, the industry score (average for the 42 certified plants) for non-penetrating percussive stunning (96.4%) and penetrative captive bolt (99.6%) meet the requirement, with the use of penetrative captive bolt being regarded as excellent. In the US, failure rates have been reported to be in the order of 0.6 – 1.2% (Grandin, 1994) with penetrating captive bolt.

During the analysis of audit findings, it was noted that the reports do not contain information on the following (unless it was specifically noted by the auditor to explain an audit finding):

- Type of head restraint
- Movement into restraint and box type
- Stunning equipment type and power
- Experience of operator
- Type of animal

However, the auditors recorded *verbatim* (on the audit template) the following possible causes of ineffective stunning when non-penetrating percussive stunning was used:

- Knocking box and stunning procedure
- Stun operative's nerves - Stated that he wanted to make sure it was effective
- Flighty animals
- New equipment - Operators not familiar with its use
- Knocking box design - No head restraint
- Leaking coupling on air hose - stunning device
- Animal agitated due to excessive time in the box
- Large Hereford
- No head restraint
- Equipment failed
- Incorrect position
- Stun operative double stunned - to make sure
- Animal moved at the last minute

To this end, further analysis of industry data (outlined in Section 5) obtained through the survey process, will establish:

- the cause of ineffective stunning in the abattoirs, using non-penetrating percussive stunning, where the KPI target was not met (<95% effective with the first shot)
- the reason for the difference in effectiveness between the stunning methods

This will enable further recommendations to be proposed, with a view to improving stunning efficacy and reducing the likelihood of individual abattoirs failing to meet the standard.

Stun to stick interval was less than 30 seconds in all abattoirs using non-penetrating percussive stunning. The industry survey will also provide information on the use of thoracic stick post neck cut. Analysis of audit data showed that for the animals assessed, there was no recovery before death through exsanguination, thus indicating that the exsanguination process (including stun to stick interval) were sufficient to induce brain death during unconsciousness produced by the stun.

6.2 Factors affecting stunning outcome when non-penetrating percussive stunning is used - as identified in the scientific literature review

Refer to literature review in Appendix 1 (Section 8.1)

7.0 Conclusions and recommendations

It was evident through a review of the scientific literature, that the main factors affecting the efficacy of non-penetrating percussive stunning were those associated with the operator, the animal, the facility and equipment used. The skill (training and experience) of the operator has a significant impact on achieving a consistent stunning outcome. The design and arrangement of the cattle handling facilities and restraint box impact on both the presentation of the animal to facilitate application of the equipment; and on the ease of handling of the animal. Generally, improved restraint leads to improved stunning efficacy. The use of high-powered stunning equipment improves effectiveness, through the delivery of a higher velocity impact to the head, and overcomes slight inaccuracies in stun position. There are also differences in animal anatomy that can affect the outcome of the stun in terms of effective induction of unconsciousness; and there are differences between stunning equipment in terms of power, ease of application and reliability.

The use of controlled head restraint and high powered stunning equipment is common in Australian cattle processing establishments, though information on specific types of restraint and stunning equipment is not available, through the analysis of external audit reports. It is recommended that this information (currently being obtained through an additional industry survey) is collated, analysed and used to refine and improve processes where existing stunning conditions do not meet the optimum conditions as identified in the literature review. The final document will be formatted for publication in relevant journal, for example, ‘Animal Welfare’.

CONCLUSIONS AND RECOMMENDATION	
1	Without good restraint, consistent accurate placement is impossible. Although research into stun parameters is warranted, it needs to be combined with the use of good head restraint. It is therefore recommended that a review of restraint methods used in AAWCS certified abattoirs is undertaken. This could be integrated into the external audit process, data is collected by the auditor and recorded on their documentation. Although good head restraint optimises stun placement accuracy, what is not known is if there is a relationship between restraint characteristics (type of equipment) and stun outcomes.
2	Recommended minimum bolt velocity parameters have been identified for penetrative captive bolt instruments, the minimum velocity required to provide an effective stun in different classes of animals, using a non-penetrating mechanical stun, is relatively unknown. It is recommended that further investigations of the interrelationships between animal factors and non-penetrating stunning equipment parameters, and the overall impact on stunning outcome are undertaken. This can be combined with an evaluation of the performance of different stunning equipment (used commercially in Australia)
3	Data on anatomical differences between animals of different breed, gender and age, should be collected and analysed and used to inform choices relating to cartridge strength, stun device characteristics and shot position. The anatomical data can be used to refine training programs and industry extension material
4	The negative welfare impacts of poor exsanguination, as they relate to possible recovery from a stun, have been identified through a number of research papers. The use of optimum exsanguination techniques in abattoirs using non-penetrating stunning needs to be investigated further.

Table 5 Recommendations following the completion of the project

8.0 Appendices

8.1 Appendix 1 - Review of the scientific literature relating to percussive stunning of cattle

1. Introduction to mechanical stunning

Stunning is carried out to ensure that animals are unconscious at the time of exsanguination, so they do not feel pain and distress as a result of the exsanguination cut.

When stunning is ineffective there is also a risk to animal welfare through:

- Pain and distress as a result of the failed application
- Shackling and hoisting a sensible animal
- Prolonged sensibility during bleeding

Effective stunning also improves operator safety as the tonic phase, during which the carcase is rigid, enables safe manipulation of the animal and effective neck cutting. At present, there are two commonly used methods for stunning cattle: mechanical stunning (most common method) and electrical stunning. In an abattoir, mechanical stunning consists of penetrative captive bolt, non-penetrating (percussive) stunning and less commonly, free bullet.
Mechanical stunning involves the application of a percussive blow in an attempt to induce cerebral concussion. A concussive state is normally associated with a sudden, brief loss of consciousness with associated loss of reflexes and memory (Shaw, 2002). Inducing unconsciousness (associated with concussion) requires the transfer of sufficient kinetic energy into the brain to disrupt normal neural function (Ommaya and Gennarelli, 1974, 1945, Holbourn, 1943, Ommaya et al., 1971, Denny-Brown, 1945, 1941, Denny-Brown and Russell, 1940, Williams and Denny-Brown, 1941). An effective mechanical stun immediately suppresses brain function, abolishing evoked responses, and pain responses, as measured by EEG (Daly and Whittington, 1989a, Daly et al., 1987, 1989b, Gibson et al., 2009a, 2009b).

The key parameters for delivering an effective stun are:

- Accurate placement - target area and direction of the percussive blow
- Sufficient kinetic energy transfer - extent and nature of the percussive blow

However, quantifying the biomechanics of concussion and outcome of a non-penetrating blow to the head is a formidably difficult task. Numerous considerations need to be taken into account, these include factor relating to the stun operator; the facility and equipment, and the animal (Table 1):

A number of recent studies have attempted to quantify the prevalence of ineffective stunning under commercial and laboratory conditions and identify possible contributing factors. In an abattoir study, 12-20% of cattle stunned using non-penetrating percussive equipment required re-stun (Hoffmann 2003, cited in von Holleben *et al*, 2010), most of which were associated with inappropriate positioning of the device; whereas laboratory studies are usually able to demonstrate good effectiveness (Gibson et al 2009[c]). It is likely that in laboratory studies there can be greater care taken over positioning of the animal's head and application of the device. This suggests that improvements in restraint and positioning of the animal's head to facilitate accurate placement of the device results in a higher incidence of effective stunning.

Table 1 Factors affecting the delivery of an effective non-penetrating stun

Factors associated with	Delivery of effective stun affected by	
Operator	- Skill - Attitude - Fatigue - Focus	- Training
Facilities and equipment	- Restraint - Flooring - Distractions - Lighting	- Stun equipment type - Stun equipment power
Animal	- Behaviour - Temperament - Anatomy (skull, scalp neural tissue)	

2. Achieving a successful stun with non-penetrating equipment

2.1 Factors associated with the stun operator

Factors associated with the stun operator relate to skill (a combination of experience and training), attitude (to the task and to animals) and focus (attention and fatigue). Individuals differ both in their attitude to animals and to the task which they are required to perform. Carrying out the stun is a complex task, which to perform correctly the operator needs to apply the stunning device a specific area of the animal's head, and fire a projectile (either through direct contact or by depressing a trigger). The task is made more complex by the fact that the optimum target position is not always clear (and can differ between animals) and can move within three planes. To accurately position a stun on the target area, the stun operator requires an ability to focus on the task and ignore distractions. Distractions in the abattoir may include those associated with the behaviour of animals, the behaviour of co-workers, pressure to complete the task quickly (throughput) and the presence of observers, for example, auditors. Distractions related to the individual's personal life can also influence on their ability to focus on the job and deliver an accurate stun.

A consistent focus of recent meat processing guidelines and industry standards is for the stun operator to demonstrate competency. Competency in a task is more than a completion of appropriate training and requires the development and demonstration of skill and knowledge. Research has shown stun operators need to complete many repetitions (Table 2) before becoming fully competent in the stunning process (Atkinson et al., 2013).

Table 2 Percentage of cattle accurately shot by each stunning operative in the study (related to task experience) Adapted from - (Atkinson et al., 2013)

OPERATOR	ACCURATE SHOTS (%)	EMPLOYMENT PERIOD
1	90	5 years
2	94	5 years
3	81	3 months
4	90	3 years
5	95	15 years

2.2 Factors associated with the facilities and equipment

2.2.1 Pre-slaughter handling and movement into restraint

The pre-slaughter environment (movement up to and into restraint) is known to be stressful to animals (Cockram and Corley, 1991, Tume and Shaw, 1992, Shaw and Tume, 1992, Hemsworth et al., 2011b). The amount of stress experienced by the animal is associated with the facilities and practices at individual abattoirs (Hemsworth and Barnett, 2001, Grandin, 2003, Hemsworth et al., 2011a). The stress experienced by the animal can be physical in nature, e.g. fatigue or injury, or psychological (Grandin, 1997), e.g. exposure to novel environments, unfamiliar animals, isolation and restraint.

The OIE Terrestrial Animal Health Code (2014) outline basic provision for all methods of restraint, where operators are required to:

- *Provide a non-slip floor within the restraint equipment.*
- *Ensure that the restraining equipment does not exert excessive pressure, thus causing the animal to struggle or vocalise.*
- *Ensure equipment is engineered to reduce the noise of hissing air and clanging metal.*
- *Ensuring equipment has no sharp edges that would harm animals.*
- *Use restraining devices appropriately and not jerk them or making sudden movements.*

Additional principles of good restraint (Von Holleben et al., 2010) include:

- *"an animal should be able to enter / to be put in the restraining device without stress;*
- *Restraining itself must cause as little stress/strain as possible;*
- *Restraining time should be as short as possible;*
- *Restraining must not cause injuries;*
- *… the restraining method must allow secure positioning of stunning devices…*
- *… a restraining device or method must suit the size and species and type of animals slaughtered.*

Numerous factors affect the application of restraint, including the animal's previous experiences in restraint (e.g. in a crush during management procedures), its size and weight relative to the restraint unit; whether it has horns; and its level of excitement or stress (Grandin, 1993, 1996, Boivin et al., 1994, 2013). The success of the restraint process will in turn influence the effectiveness of the stun applied. During mechanical stunning, Gregory *et al.* (2007) found that 19% of excited cattle showed a shallow depth of concussion, or required re-stun; compared with 8% of non-excited cattle.

2.2.2 Head restraint to facilitate stunning

Head restraint equipment takes many forms, with the simplest being a shelf at the front of the box, which effectively makes it more difficult for the animal to lower its head once it has been moved into position. This type of restraint is usually more effective if it is combined with a rump pushing device to encourage the animal to move forward prevent backwards movement, which could allow the animal to drop its head below the shelf. Other systems incorporate more active head restraint, where the head is captured in neck bails (prevent backwards and side to side movement), sometimes combined with a chin-lift (preventing head movement in the vertical plane).

Many authors have cited absence or inappropriate head restraint as a significant factor contributing to incorrect stun position or ineffective stuns. Gouveia *et al.* (2009) found that in premises where no head restraint was used, up to 50% of stuns were applied incorrectly and could potentially produce an ineffective stun. Inaccurate shot position (not always resulting in ineffective stunning) has also been reported as 8.0% (Atkinson et al., 2013), 51% (Gallo et al., 2003), 7.8% (Fries et al., 2012) and 35% (von Wenzlawowicz et al., 2012) where no neck or head restraints were used. Bertoloni and Andreolla (2010) compared a standard knocking box, without a chin lift, with an automated restraint system that included a chin lift. They found that the automatic restraint system resulted in greater shot accuracy and significantly ($P<0.0001$) reduced the number of animals requiring re-stun. A tightly restrained head (for example, combination of a neck yoke and chin lift) would be expected to allow very accurate shot placement; however, tight head capture can be very stressful to the animal, particularly if the duration is prolonged. It is anticipated that improvements in head restraint would improve accuracy in shot position.

2.2.3 Mechanical stunning equipment parameters

The object of mechanical stunning is to transfer kinetic energy from the moving bolt or percussive head to the brain, physically shaking the brain within the skull cavity, resulting in concussion. Although force and kinetic energy are interrelated, the important factor in inducing insensibility is the amount of kinetic energy transferred to the brain (Daly et al. (1987); Finnie (1997)), this is influenced to the greatest extent by the velocity of the bolt. Slight inaccuracies in shot position can be overcome by the use of high-powered devices, which have the highest velocity and hence deliver greater kinetic energy (Gregory, 2007, von Wenzlawowicz et al., 2012).

It is a common belief that non-penetrating mechanical stun devices are more likely to produce ineffective stuns than penetrating devices. However, significant levels of re-stunning have also been observed when penetrative captive bolt devices are used. Von Holleben *et al* (2010) estimated up to 15% ineffective stunning with penetrative mechanical stunning. Gouveia *et al* (2009) found that only 68.2% of 2800 captive bolt stuns in a Portuguese cattle slaughterhouse were effective, and that the efficiency decreased with age of animal ranging from 89.1%, in cattle younger than 12 months of age, to 50.3% in animals over 30 months of age. They also found that stunning was more effective in males than females. The abattoir concerned used a conventional stunning box without head or body restraint. Munoz *et al.* (2012) recorded effective stuns with a single shot in 86.7% of 1025 cattle stunned using a pneumatic non-penetrating percussive stunner (Jarvis USSS-2).

The size of the impact head of non-penetrating stunners also has an affect on stunning efficacy, through the influence on the amount of energy transferred to the brain. McPhail and Cain (1985) reported a reduction in efficacy of stun (percentage of animals stunned with a single shot), with an increasing surface area.

Endres (2005) (cited in von Holleben *et al.* 2010) compared two pneumatically operated non-penetrating stunners, and concluded that it was not possible to find an optimal relationship between the velocity (force) of the impact, and the size of the impact head that would achieve effective stunning without causing skull fractures. Gibson *et al*. (2015) studied a range of commercially available mechanical stunning equipment and confirmed previous advice, that repeat firing over extended periods leads to heat generation within the barrel and breakdown of the rubber buffers; and that poor maintenance of the equipment will detrimentally affect performance.

2.3 Factors associated with animal type and behaviour

2.3.1 Anatomical differences between animals

A key parameter for delivering an effective non-penetrating stun is accurate placement of the stunning device. It is essential that the device is applied so that sufficient kinetic energy is transferred from the moving impact head of the instrument to the brain. The optimum target area differs between species, and within species.

Figure 1 Anatomical difference is marked between cattle (*Bos indicus and Bos taurus*) and buffalo

The anatomical difference is most marked between species, as evidenced by the differences between buffalo and cattle (Figure 1), but even within a species differences in bone thickness and density occur as influenced by age, gender and breed etc. Research has demonstrated that ineffective stunning occurs more frequently in older (McPhail and Cain, 1985), male animals (Daly and Whittington, 1989b) when the same stunning parameters are used. This is likely to be related to greater skull thickness in the target area.

Bos indicus and *Bos taurus* animals are different in their appearance, particularly around the poll area and relative position of the ears and eyes. Most published research on mechanical stunning is related to *Bos taurus* animals, with recommendations for cartridge strength and shot position that may not be appropriate when stunning *Bos indicus* animals.

The recommended shot position for mechanical stunning has changed overtime (Figure 2a,b,c). McPhail & Cain (1985) refer to a position at the intersection between the medial canthus of eye and the opposite midpoint of horn. The Australian Land Transport Standards and Guidelines (2012) and provides guidance on the recommended position for shooting with a penetrative captive bolt pistol (Figure 2a (position A and B) or firearm (Position A, B or C) in horned cattle. Target position A is a frontal stunning 34yposition with instruction as follows *'captive bolt should be directed at a point midway across the forehead at the intersection of imaginary lines that join each eye* (indicated as lateral canthus on the diagram) *with the opposite horn or the point where the horn would be* (indicated as midpoint of the horn on the diagram). *The line of fire should be aimed into the skull towards the centre of the brain or spinal cord'.* Figure 2b is from the Model Code of Practice for the Welfare of Animals (Livestock at Slaughtering Establishments) 2001. This shows the target position as the intersection between the top of the eye and the base of the opposite horn. It is thought that that an intersection between the lateral canthus of the eye and the opposite horn gives a better stunning outcome than the medial canthus, when a penetrative captive bolt is used.

Figure A

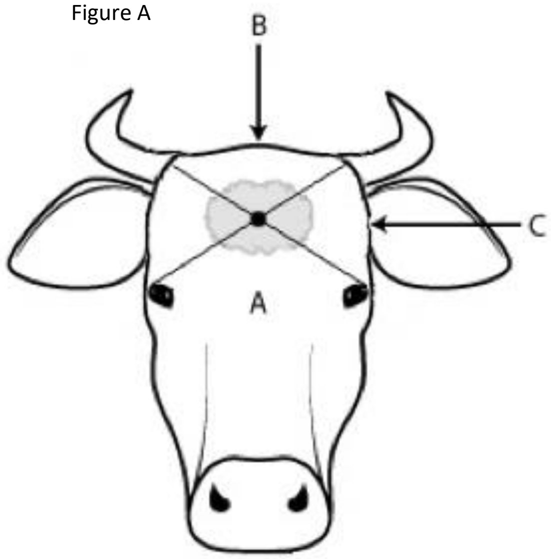
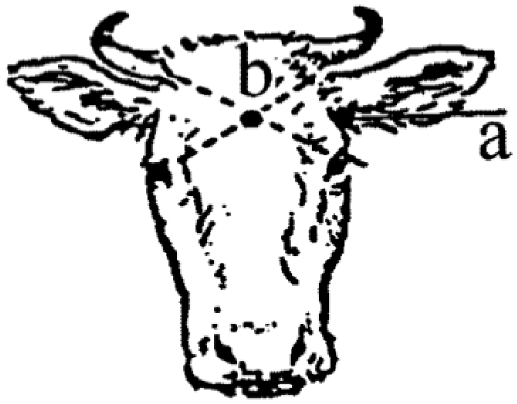


Figure B



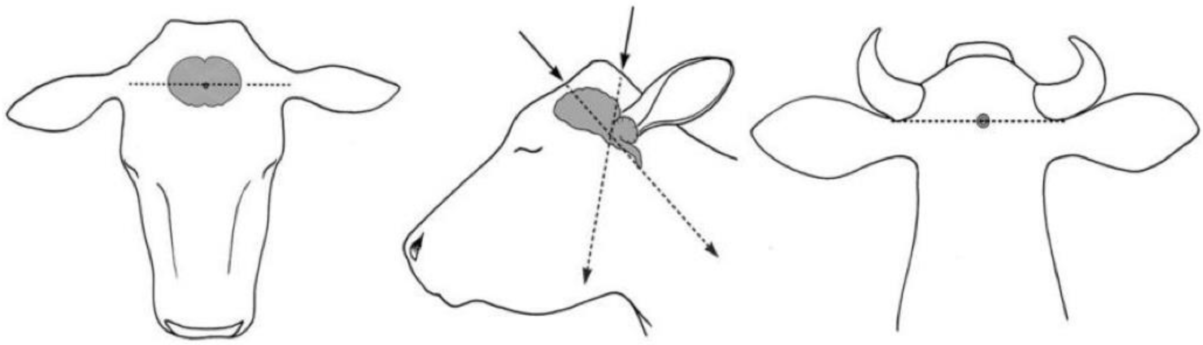


Figure C

Figure 2 (a) Australian Land Transport Standards and Guidelines (2012) for shooting horned cattle with a penetrative captive bolt pistol (position A and B) or firearm (Position A, B or C).
(b) Model Code of Practice (Slaughter) where position A indicates the recommended position for temporal shots (firearms only) and position B indicates the recommendation for the frontal position (Captive bolt and firearm)
(c) MLA depicts a frontal position located centrally on the animal's head on a line drawn between both ears, or a 'poll position', positioned behind the bony ridge and aiming towards the jaw

The type of mechanical stunning device used also influences stun position, with the recommended position for applying a non-penetrating mechanical stun being slightly different from that required for a penetrative mechanical stun. The Humane Slaughter Association (HSA, 2006) recommend that a non-penetrating percussive stun is positioned approximately 2cm above the crossing point of two imaginary lines between the eyes and the base of the opposite horn. Slight deviations from this target impacts profoundly on stun effectiveness (HSA, 2006). The larger surface area impacting the head as compared to a penetrative captive bolt may lead to be a loss of kinetic energy, absorbed through cushioning by the skin, resulting in reduced stun efficacy (Endres, 2005).

In two recent studies (Hoffmann, 2003) (Endres, 2005) non-penetrating captive bolt stunning was tested under commercial conditions and found that the percentage of successful first stuns was 83.3-88% with the rate of re-stunning increasing considerably if the shooting position deviated from the midline. Examination of the heads showed profound injuries of the frontal bone in the impact area of the bolt including inner and outer bone laminae and partly the dura mater. All brains examined also had haemorrhages of varying extent beneath the impact site and around the brain stem. It was concluded that it was not possible to find the optimal relation between dimension of the concussive head of the stunner and dose of the force of the blow, to achieve sufficient effectiveness without fracturing the skull. This was because especially in the young bulls the shape and hairiness of the heads showed huge variations. Fracturing of the skull resulted in less effective stunning (Endres, 2005).

Figure 3 Animal factors such as the presence of horns have an indirect affect on stunning efficacy through their influence on restraint methods

2.3.2 Differences in behaviour and temperament

Animals also vary in terms of temperament, and their reactions to external stimuli (Voisinet et al., 1997, Lanier et al., 2000, Bourguet et al., 2015, Boissy and Bouissou, 1995, Grandin, 1993). Some animals are by nature quiet and docile, others more excitable. It has been shown that regular handling in familiar surroundings can help to reduce the escape behaviour of excitable animals and improve the safety of handlers. Well-handled animals may be easier to position for effective stunning, as they are less likely to move unpredictably within the stun box, however, they can be difficult to move into the stun box, as they often refuse to walk forward and enter the box. Excitable animals may move quickly into the stun box, usually in an attempt to escape or may retreat before the rear gate is closed (Ewbank, 1961, Ewbank et al., 1992). Even when enclosed in the stun box, the animal may become agitated in an attempt to escape, or to avoid the approach of the stun operator, which can make accurate application of the stunning device difficult

3. Assessment of effective stunning

3.1 The effect of non-penetrating percussive stunning on the brain: extent and duration of unconsciousness

Concussion is regarded as one of the most puzzling of neurological disorders, particularly in the nature of its pathophysiology. The main symptom of concussion is an abrupt loss of consciousness, characterised by immediate collapse. The period of unconsciousness can vary and is followed by a spontaneous recovery of awareness, in the absence of gross damage to neural tissue. This transient state of unconsciousness is also associated with a number of other clinical observations, including, loss of rhythmic breathing (respiratory arrest) and abolition of various reflex functions (including corneal reflex). The outcome of a non-penetrating stun lies somewhere between 'ineffective' (if the blow is not severe enough to induce concussion) through to death (if the degree of haemorrhage and internal contusions prevents recovery).

The duration of insensibility produced by the stun is also important. To ensure protection of animal welfare, the animal must remain unconscious throughout exsanguination, until death ensues. Although methods for confirming unconsciousness following non-penetrating stunning are well defined), there have been few studies on the duration of unconsciousness produced by non-penetrating percussive stunning. However, all research appears to support the concept that an increase in the concussive force and resulting damage increases the duration of unconscious to the point of irreversibility. In a study on lambs and calves, the majority showed signs of recovery (Blackmore and Delany, 1988). These signs and the development of righting reflexes did not usually occur in less than 2 minutes (Blackmore, 1979). In calves, outward signs of effective non-penetrating percussive stunning were described as the appearance of 5 to 15 seconds of tonic convulsions and spasms prior to relaxation, or as extensor rigidity and some generalised muscular tremors, followed by slow hind leg movements. Absence of rhythmic breathing lasted for up to 35 seconds, and absence of righting behaviour lasted for a minimum of 60 seconds (Lambooij et al., 1981).

Little other data on duration of stun is available, but there are many references to maximum stun to stick intervals in international standards and guidelines, for example the OIE Terrestrial Animal Health Code (OIE, 2014), in recognition of the potential for return to consciousness. The European Union has ruled that non-penetrating percussive stunning must not be used on animals greater than 10kg liveweight, due to challenges in ensuring death through exsanguination has occurred within 20 seconds of the stun, in larger animals (EC, 2009).

The earliest attempt to quantify the effects of experimental concussion on the EEG was made by Williams and Denny-Brown (1941). The result of the experiment showed an immediate generalized loss of amplitude in the EEG. By the end of the recording period, the EEG patterns began to return to normal baseline patterns and the return of eye reflex activity coincided with the return of normal EEG activity.

3.1 Practical indicators used to assess depth of concussion after non-penetrating percussive stunning

It is generally agreed in the context of anaesthesia and slaughter, that physical collapse and the lacking of goal directed movements are important signs with regard to evaluation of consciousness. In the conscious animal the cerebral cortex integrates both functions (posture and movement). Therefore physical collapse can indicate that the cortex is no longer able to control postural stability (Muir, 2007). Reflexes especially those including the cranial nerves are useful for assessing brain function, this is because the cranial nerves enter the brain above the level of the spinal cord. If a cranial nerve reflex is positive, the pathway that the cranial nerve reflex takes through the brain is still functional. If all negative, they are good indicators of impaired midbrain or brainstem activity and unconsciousness can be inferred (Gregory, 1998) (Figure 4).

Effective stunning can therefore be monitored from immediate collapse and prompt, persistent absence of rhythmic breathing. The muscles in the back and legs go into spasm, forelegs and hindlegs are flexed, the forelegs straightening after a few seconds. Signs that indicate a shallow depth or concussion include flaccid muscles immediately after stunning, return of rhythmic breathing and rotated eyeballs. Return of rhythmic breathing happens if stunning is insufficient or bleeding is too late (Gregory, 1998). These indicators of effective stunning are supported under experimental situations by measurements of electroencephalography (EEG) and electrocorticography (ECoG) (EFSA, 2004).

Figure 4 Testing the corneal reflex can be used to assess depth of concussion after non-penetrating stunning

4. Exsanguination

If a reversible form of stunning is used bleeding becomes particularly important for ensuring that the whole process is humane. The aim is to bleed the animal (resulting in a state of irreversible unconsciousness) before any possible recovery from the stun. In other words, one form of unconsciousness (stun) leads straight into another (blood loss) without the animal recovering consciousness at any stage. In cattle, sticking should be performed within 12 seconds of non-penetrating captive bolt stunning (EFSA, 2004).

Anil *et al.* (2004, 2006) demonstrated that the bleed out rate and total blood loss did not differ between slaughter without stunning and captive bolt stunning in cattle; and between slaughter without stunning, captive bolt stunning and electrical stunning in sheep. Similarly, measurements of residual blood content of meat from animals subjected to different slaughter processes failed to demonstrate significant differences (Warriss, 1977, 1978, 1984, Warriss and Leach, 1978).

However, the technique used for exsanguination does influence rate of bleed-out. For example, Gregory *et al.* (2012) found, in cattle, that neck cutting at the level of cervical vertebra 1 (C1) was less likely to result in vessel occlusion and early cessation of bleeding that neck cutting performed at the level of C2 – C4. Mulley *et al.* (2010) found that, in deer, blood loss was faster in animals that had received a 'thoracic stick', compared with those that received the neck or stick, which in turn was faster than in those that received an 'Incomplete Gash' stick, in which only the vessels on one side of the neck were cut.

5. Conclusion

The main factors affecting the efficacy of non-penetrating percussive stunning were those associated with the operator, the animal, the facility and equipment used. The skill (training and experience) of the operator has a significant impact on achieving a consistent stunning outcome. The design and arrangement of the cattle handling facilities and restraint box impact on both the presentation of the animal to facilitate application of the equipment; and on the ease of handling of the animal. There are differences in animal anatomy that can affect the outcome of the stun in terms of effective induction of unconsciousness; and there are differences between stunning equipment in terms of power, ease of application and reliability.

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8.2 Appendix 2
AMPC Snapshot – Review of percussive stunning (2016/1040)
Date of issue: July 2016

Project description

The objective of this project was the completion of a review of published scientific data and industry findings related to the use of non-penetrative percussive stunning overseas, to determine optimum stunning conditions for adaptation in Australia. The term 'Percussive stunning' is used to describe non-penetrating percussive stunning (also referred to as concussion stunning).

Project content

Stunning is carried out to ensure that animals are unconscious at the time of exsanguination, so they do not feel pain and distress as a result of the exsanguination cut. Non-penetrating percussive stunning is used widely for stunning cattle in Australian abattoirs and when correctly executed, it induces a state of concussion during which the animal is unconscious. However, in the EU, non-penetrating percussive methods are not permitted for stunning livestock, with the exception of small ruminants (<10kg). The change to the EU regulation was based primarily on an EFSA report (2004), which cited a field study showing that non-penetrating stunning had a high failure rate under commercial conditions in two German cattle abattoirs. The literature review

The report also identified the key technical issues affecting the use of non-penetrating percussive stunning in Australia, by review of the audit information from the Animal Welfare Certification Scheme (AAWCS).

Project outcome

The review identified key areas for future R&D to support the continued use of non-penetrating percussive stunning in Australia. This included:

- Further investigations into the interrelationships between animal factors and non-penetrating stunning equipment parameters, and the overall impact on stunning outcome should be undertaken. This can be combined with an evaluation of the performance of different stunning equipment (used commercially in Australia)
- Data on anatomical differences between animals of different breed, gender and age, should be collected and analysed and used to inform choices relating to cartridge strength, stun device characteristics and shot position.
- Without good restraint, consistent accurate placement of a non-penetrating percussive device is impossible. Although research into stun parameters is

warranted, it needs to be combined with the use of good head restraint. It is therefore recommended that a review of restraint methods used in AAWCS certified abattoirs is undertaken.

- The negative welfare impacts of poor exsanguination, as they relate to possible recovery from a stun, have been identified through a number of research papers. The use of optimum exsanguination techniques in abattoirs using non-penetrating stunning needs to be investigated further.

Benefit for industry

The majority of cattle processors in Australia use mechanical equipment (such as penetrative or non-penetrative concussion devices) as their primary stunning method. When correctly execute, non-penetrating percussive stunning induces a state of concussion during which the animal is unconscious. The project has demonstrated that in Australia the conditions under which non-penetrating stunning is used are somewhat different to those observed in some of the EU field surveys, with the use of controlled head restraint and high velocity pneumatic stunners commonplace. The recommendations from this study, include the need for further investigation into the effectiveness of restraint and application of appropriate stunning parameters in all AAWCS certified abattoirs, to ensure that optimum conditions for effective stunning are consistently applied.

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8.3 Appendix 3

Industry Survey Template – See PDF