RESEARCH REPORT
ANIMAL WELFARE

TITLE: On-farm validation of captive bolt technology as a single stage euthanasia method – NPB #09-196 revised

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INDUSTRY SUMMARY

There has been limited published research on the use of penetrative or non- penetrating captive bolt for euthanasia of swine. The CASH Dispatch Kit is a heavy duty cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides a non-penetrating captive bolt muzzle for piglets, and a variety of penetrating bolt assemblies for pigs ranging from large nursery-age pigs to mature breeding stock. The overall objective of this project was to determine effectiveness of a single application of the captive bolt device for euthanasia of pigs at different ages.

The first experiment explored effectiveness of the Cash Dispatch captive bolt device when applied to anesthetized pigs in a controlled laboratory setting, and also to evaluate the association between traumatic brain injury to anatomical regions of the brain and effectiveness of captive bolt technology for euthanasia of pigs at different ages. Forty two pigs, six from each of 7 weight classes (2-3kg, 7.5-10 kg, 15-20 kg, 30-40 kg, 100-120 kg, 200-250 kg, >300 kg) were enrolled. Each pig was anesthetized, and then euthanized with the "Cash" Dispatch Kit. Death was determined according to time to last heartbeat and respiratory function. Postmortem dissection was used to determine the presence of hemorrhaging and the extent of traumatic brain injury. All 30 pigs in the 5 lightest weight classes were effectively euthanized. Four of the 12 pigs in the heaviest weight classes required a secondary method. For pigs that were successfully euthanized with a single shot, movement typically ceased within 1 to 2 minutes. However, there was tremendous variability in this response, and casual observation indicated that many pigs displayed repeated bouts of involuntary movement and quiescence. Heartbeat typically ceased after approximately 4 minutes, taking approximately twice a long to cease when compared to last movement. Weight class associated with time to last heartbeat ($p=0.0071$), such that the duration of heartbeat decreased by 26 seconds for each increase in weight class

All pigs that were successfully euthanized with a single application of the CASH Dispatch captive bolt device displayed haemorrhage in all 5 neuroanatomical regions assessed (cerebral cortex, cerebellum, thalamus, pons and medulla). However, 2 of the 4 pigs requiring a secondary euthanasia step lacked haemorrhage in the

medulla and pons. Interestingly, although all pigs successfully euthanized with a single shot of the penetrating captive bolt displayed traumatic brain injury in the cerebral cortex, only 1 pig (weight class 4) showed traumatic brain injury in any of the other 4 regions of the brain.

In the second experiment, the effectiveness was assessed when the Cash Dispatch captive bolt device was used by stockpeople on commercial farms. Two hundred and ten pigs in the same 7 weight classes were enrolled in the trial. Fifteen stockpersons were enlisted from a single production company to perform euthanasia. There were 202 pigs (97%) that were effectively euthanized with a single application of the "Cash" Dispatch Kit. Seven pigs (2 sows and 5 boars) in the heaviest weight classes required a second shot. Weight class was significantly associated with the need for a second shot (P=0.006). Stockperson was also associated with the need for a second shot (p=0.0048), but there were no differences between sows and boars. Two-thirds of the pigs that required a second shot vocalized (p=0.0038). Similarly, two-thirds of pigs that required a second shot displayed respiration after the initial shot (p=0.00002). However, vocalization and respiration were also observed in pigs that were successfully euthanized, indicating that neither is a reliable predictor of euthanasia success.

Based on expected slaughter standards published by the American Meat Institute (AMI, 2010), insensibility must be achieved 95% of the time when using a captive bolt gun in order to obtain a passing score on the animal welfare audit. In Experiment 1, the Cash Dispatch Kit successfully euthanized 100% of the anesthetized pigs in the 5 lowest weight classes with a single application. However, 8 of the 12 (66%) pigs in the mature weight classes (200+ kg) required a secondary method. The manufacturers adjusted the device following the results from Experiment 1, in terms of increasing the cartridges for mature animals, and decreasing the charge for the smallest weight class. In Experiment 2, 97% of all pigs were successfully euthanized with a single application of the modified Cash Dispatch device, and again variability occurred in the mature weight classes (>200kg) in which 10% of the animals required a second shot. In the on-farm study, application of a second shot was sufficient to ensure euthanasia, and can be an alternative to exsanguination (bleeding) or pithing.

There were associations between stockperson and a number of outcome variables, including the need for a second shot. However, stockperson was confounded with weight class, since individuals worked in particular stages of production, and hence further research is needed to clearly understand this factor. Our casual observation suggests that landmarks on the pig head were usually correctly identified, but ensuring that the pistol was flush against the head at a correct angle was likely to affect efficacy. Restraint of the head through snaring appeared to be important for both efficacy and safety, rather than restraint in a chute or stall.

We conclude that the Cash Dispatch captive bolt device is effective as a single step euthanasia method for pigs <200kg. For mature animals, further refinements in terms of equipment design and/or application by stockpeople are needed to ensure reliable performance with mature animals. Stockpeople should be prepared to administer a second shot swiftly when euthanizing mature pigs with a captive bolt device.

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KEY WORDS: euthanasia, swine, penetrating captive bolt, non-penetrating captive bolt, insensibility, animal welfare

SCIENTIFIC ABSTRACT

There has been limited published research on the use of penetrative or non- penetrating captive bolt for euthanasia of swine. The CASH Dispatch Kit is a heavy duty cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides a non-penetrating captive bolt muzzle for piglets, and a variety of penetrating bolt assemblies for pigs ranging from large nursery-age pigs to mature breeding stock. The overall objective of this project was to determine effectiveness of a single application of the captive bolt device for euthanasia of pigs at different ages.

The first experiment explored effectiveness of the Cash Dispatch captive bolt device when applied to anesthetized pigs, and also to evaluate the association between traumatic brain injury to anatomical regions of the brain and effectiveness of captive bolt technology for euthanasia of pigs at different ages. Forty two pigs, six from each of 7 weight classes (2-3kg, 7.5-10 kg, 15-20 kg, 30-40 kg, 100-120 kg, 200-250 kg, >300 kg) were enrolled. Each pig was anesthetized, and then euthanized with the "Cash" Dispatch Kit. Death was determined according to cessation of cardiac and respiratory function. Postmortem dissection was used to determine the presence of hemorrhaging and the extent of traumatic brain injury. All 30 pigs in the 5 lightest weight classes were effectively euthanized. Four of the 12 pigs in the heaviest weight classes required a secondary method. All pigs that were successfully euthanized with a single application of the CASH Dispatch captive bolt device displayed haemorrhage in all 5 neuroanatomical regions assessed (cerebral cortex, cerebellum, thalamus, pons and medulla). However, 2 of the 4 pigs requiring a secondary euthanasia step lacked haemorrhage in the medulla and pons. Interestingly, although all pigs successfully euthanized with a single shot of the penetrating captive bolt displayed traumatic brain injury in the cerebral cortex, only 1 pig (weight class 4) showed traumatic brain injury in any of the other 4 regions of the brain.

In the second experiment, the effectiveness was assessed when the Cash Dispatch captive bolt device was used by stockpeople on commercial farms. Two hundred and ten pigs in the same 7 weight classes were enrolled in the trial. Fifteen stockpersons were enlisted from a single production company to perform euthanasia. There were 202 pigs (97%) that were effectively euthanized with a single application of the "Cash" Dispatch Kit. Seven pigs (2 sows and 5 boars) in weight classes 6 and 7 required a second shot. Weight class was significantly associated with the need for a second shot (P=0.006). Stockperson was also associated with the need for a second shot (p=0.0048), but there were no differences between sows and boars. Two-thirds of the pigs that required a second shot vocalized (p=0.0038). Similarly, two-thirds of pigs that required a second shot displayed respiration after the initial shot (p=0.00002). However, vocalization and respiration were also observed in pigs that were successfully euthanized, indicating that neither is a reliable predictor of euthanasia success.

We conclude that the Cash Dispatch captive bolt device is effective as a single step euthanasia method for pigs <200kg. For mature animals, further refinements in terms of equipment design and/or application by stockpeople are needed to ensure reliable performance with mature animals. Stockpeople should be prepared to administer a second shot swiftly when euthanizing mature pigs with a captive bolt device.

INTRODUCTION

Mechanical methods of euthanasia have distinct welfare advantages, since when the methods are employed correctly animals are rendered instantly unconscious and hence unable to experience pain, fear or distress (Millman, 2010). When personnel are skilled and equipment is well maintained, death is rapidly and humanely induced, but these methods can be aesthetically disturbing for some people (AVMA 2007). Mechanical methods are often the most practical option for free roaming swine, as may occur during natural disasters or roadside accident when proper handling equipment is unavailable. Currently, blunt force trauma is the most common method for euthanasia of neonatal and nursery pigs. However, there has been limited published research on the use of penetrative or non- penetrating captive bolt for euthanasia of swine (Irwin, 2010).

Mechanical euthanasia methods are based on impact of the skull with a solid object to disrupt brain function through (1) laceration or crushing of brain tissue, (2) shock waves producing axonal injury, and (3) temporary cavitation (EU Scientific Veterinary Committee, 1997). Postmortem examinations have shown that head injuries are likely to be instantly fatal when haemorrhage occurs in the brain stem (Gregory, 2004). 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. Perception of discomfort, fear, anxiety and depression all involve thalamic input to the forebrain and limbic system. The reticular formation in the brain stem coordinates consciousness, relaying signals from the cerebral cortex, thalamus and hypothalamus, as well as anterolateral funiculus, trigeminal nucleus and cranial nerves. Immediate unconsciousness occurs upon damage to the reticular formation and other parts of the brain stem, progressing to death. Brain death is more accurately assessed using brainstem reflexes rather than spinal reflexes. Four cranial-nerve reflexes that are commonly used for assessing brainstem death are:

1. Lack of eyeblink response when the cornea is touched
2. Pupils are fixed in diameter and do not contract when a light beam is shone into the eye
3. Lack of eye movement when ice water is infused into the ear
4. No gag reflex to stimulation of the trachea

The CASH Dispatch Kit is a heavy duty cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides a non-penetrating captive bolt muzzle for piglets, and a variety of penetrating bolt assemblies for pigs ranging from large nursery to adult swine. In addition, the kit includes all necessary equipment for basic cleaning and maintenance of the unit. The goal of controlled blunt force trauma is to provide an exacting force at the precise location necessary to cause massive traumatic brain injury (including to the brainstem) resulting in the immediate loss of consciousness and a humane death.

OVERALL OBJECTIVES:

1. ***Experiment 1: Evaluation of a captive bolt device, the CASH Dispatch captive bolt device, as a single step euthanasia method in a laboratory setting***.
   1.1. To determine effectiveness of a single application of the captive bolt device for euthanasia of anesthetized pigs at different ages
   1.2. To evaluate the association between traumatic brain injury to anatomical regions of the brain and effectiveness of captive bolt technology for euthanasia of pigs at different ages

2. ***Experiment 2: Evaluation of a captive bolt device, the CASH Dispatch Captive Bolt Gun, as a single step euthanasia method in a commercial production setting***
   2.1. To determine effectiveness of a single application of the captive bolt device for euthanasia of conscious pigs at different ages
   2.2. To investigate differences between employees for captive bolt euthanasia of swine

MATERIALS AND METHODS

Experiment 1: Evaluation of a captive bolt device, the CASH Dispatch captive bolt device, as a single step euthanasia method in a laboratory setting

Forty-two commercial pigs, 6 in each of 7 weight classes (Table 2) were transported to the Iowa State University Veterinary Diagnostic Laboratory. Within each weight class, half of the pigs were male (barrows or boars) and half were female. In addition, attempts were made to select pigs with both plank-face and dish-face skull formations within the large weight classes (classes 5,6 and 7) to provide representative samples of typical US swine. Pigs were selected for culling by farm staff, and came from the same commercial source farm in Missouri.

Pigs were individually moved out of the lairage pen and into a central handling area by the researchers using a hog sorting board. Pigs weighing 30 kg or greater were restrained with a snare and anesthetized by an ISU veterinarian using a combination of xylazine (VetTek, lot #54016TT, exp 11/11), ketamine (Ketaset, lot #5401C9X, exp. 02/12) and telazol (Fort Dodge Animal Health, lot 13271, exp 06/20/12). The dose was determined by the attending veterinarian (KS) based on the manufacturer's recommendations. The attending veterinarian assessed the successful induction of anesthesia by lack of pig response to the following sensibility tests: (1) eye blink response (light touching of the cornea with a finger to detect the presence of involuntary blinking), (2) withdrawal response to a pinch on the coronary band of the leg and (3) withdrawal response or movement in response to a pinch on the snout. Once successful induction of anesthesia was confirmed, pigs were placed in a sternal lying posture when possible. This was not possible with 200 + kg pigs due to their physical weight and size.

All captive bolt euthanasia was performed by one technician (JW), using the "CASH" Dispatch Kit (Accles and Schevolke, Sutton Coldfield, West Midlands, UK) - a heavy duty, .25 caliber cartridge propelled captive bolt device with interchangeable muzzle assemblies (Figure 1). The unit provided 4 bolt head styles and 5 power cartridges (Table 1), coordinated to bolt head type and weight class of the pig (Table 2). For pigs in weight classes 3 to 7 which were euthanized with a penetrating captive bolt, landmarks for bolt placement were drawn on the skull using a black felt tip marker 1 finger width above the eye based on the industry guidelines (AVMA, 2007; AASV, 2009). For pigs in weight classes 1 and 2, which were euthanized with the non-penetrating bolt, the gun was centered on the piglet's forehead. The captive bolt gun was loaded, placed perpendicular and firmly against the pig's skull in the proper location and fired. A researcher immediately confirmed insensibility through corneal reflex, snout and toe pinch. Electrocution was used as a secondary euthanasia method for animals that were not confirmed dead at the pre-determined 10-min ceiling after the shot was fired, or if signs of return to sensibility occurred.

Euthanasia was assessed for immediate and sustained insensibility, cessation of (involuntary) movement, and cessation of cardiac function. Respiration and (involuntary) vocalizations were also recorded. Once clonic movements ceased and researchers could safely approach the animal, the presence of a detectable heartbeat was palpated and time to last heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heart beat. Presence of rhythmic breathing was observed visually and acoustically. A second researcher documented the presence of audible noises or vocalizations, including gasps, groans or grunts, as well as the time to last tonic (stiffening) or clonic (paddling) movement. Each animal was pronounced dead when both cessation of heartbeat and respiration were confirmed.

Skulls were radiographed on the sagittal plane to determine bolt penetration and trajectory. A pilot study using cadavers indicated that barium placed on the skull at the landmark for penetrating captive bolt administration facilitated identification of the skull fragment that was projected into the brain with the bolt trajectory.

Cadavers were then placed in a 10% formalin solution for 16-17 days to achieve partial fixation. For pigs in weight classes 3 to 7, heads removed following exsanguination and unnecessary skin, tissue and bone removed. Pigs in weight classes 1 and 2, which were euthanized with the non-penetrating head, remained intact. Incisions in the skin covering the skull cavity facilitated penetration of the formalin solution throughout the brain. Upon removal from the formalin solution, skulls were split longitudinally for pigs in weight classes 3-7

(Figure 2), and neuroanatomical structures (cerebral cortex, thalamus, cerebellum, pons and medulla) were macroscopically scored for haemorrhage and traumatic brain injury (modified from Millar and Mills, 2000). For pigs in weight classes 1 and 2, euthanized with the non-penetrating captive bolt, skin was cut from the top of the skull and bone fractures removed with tweezers to expose the brain.

Descriptive associations between outcome variables (time to last movement, time to last heartbeat) and weight class were analysed using linear models, first utilizing a Lack of Fit test to determine if weight should be considered a continuous or factor variable. General linear models were used to identify correlations between weight class and then outcome variables. The small sample size precludes statistical analysis for associations between weight class and traumatic brain injury, and hence descriptive data is presented.

Experiment 2: Evaluation of a captive bolt device, the CASH Dispatch Captive Bolt Gun, as a single step euthanasia method in a commercial production setting

Two hundred and nine commercial pigs from 5 integrated production sites within Missouri were enrolled in the trial. The sites included one farrowing unit, 1 nursery site, 2 finishing sites and a boar stud.Pigs were selected by farm staff based on weight and sex. Further criteria for the selection of pigs included variations in skull shapes (dish shape and plank shape) within the mature weight classes and that the animals should be cull animals with no damage, injury or deformity to the head. Seven weight classes were included (Table 2). All captive bolt euthanasia was performed using the "CASH" Dispatch Kit (Accles and Schevolke, Sutton Coldfield, West Midlands, UK) - a heavy duty, .25 caliber cartridge propelled captive bolt device with interchangeable muzzle assemblies (Figure 1). The unit provided 4 bolt head styles and 5 power cartridges (Table 1), coordinated to bolt head type and weight class of the pig (Table 2).

Fifteen stockpersons from 1 company were enlisted from the 5 production sites. Previous experience of the stockpersons ranged from first time users to stockpersons who used captive bolt guns weekly. Instruction was provided by 1 researcher to all stockpersons before each euthanasia session began. Stockpersons were instructed on pig anatomical placement based on the current industry guidelines. If signs of sensibility were present including failure to collapse, and the presence of eye blink response, a second shot was immediately applied.

Euthanasia was assessed for immediate and sustained insensibility, cessation of (involuntary) movement, and cessation of cardiac function as described in Experiment 1. In addition, number of kicks by a single hind leg were recorded using a hand counter, and a researcher documented casual observations about accuracy of the placement of the shot.

Contingency tables, with Fisher's Exact Tests, were used to explore associations between the need for a second shot with weight class, sex and stockperson. Descriptive associations between outcome variables (time to last movement, time to last heartbeat) and weight class were analysed using linear models, first utilizing a Lack of Fit test to determine if weight should be considered a continuous or factor variable. General linear models were used to identify correlations between weight class and then outcome variables.

RESULTS

Experiment 1: Evaluation of a captive bolt device, the CASH Dispatch captive bolt device, as a single step euthanasia method in a laboratory setting

All pigs were anesthetized successfully, and remained insensible or unconscious following application of the captive bolt device. Bleeding during euthanasia was common through the nostril, ear or site of bolt

penetration, occurred with most if not all pigs. Half of the pigs in weight class 1 displayed protrusion of the eyes following application of the non-penetrating captive bolt.

Thirty-eight pigs were effectively euthanized with a single application of the "CASH" Dispatch Kit. Four mature pigs required a second euthanasia step due to presence of rhythmic breathing at the 10 min ceiling (Table 3). Pulse was difficult to detect in mature animals, as the pulse became faint and erratic during the dying process. Animals requiring a second shot comprised both sexes and both "dish" and "plank" skull shapes.

For pigs that were successfully euthanized with a single shot, movement typically ceased within 1 to 2 minutes. However, there was tremendous variability in this response, and casual observation indicated that many pigs displayed repeated bouts of involuntary movement and quiescence during which neither tonic nor clonic movements occurred. A lack of fit test supported inclusion of weight class as a continuous variable in the model, but weight class did not have a significant effect on time to last movement ($p=0.59$). Mature pigs (weight classes 6 and 7) appeared to display the greatest variation in response (Figure 3).

Cardiac function typically ceased after approximately 4 minutes. Weight class was included as a continuous variable for time to last heartbeat, and was significantly associated with time to last heartbeat ($p=0.0071$). The duration of heartbeat decreased by 26 seconds for each increase in weight class (Table 4).

All pigs that were successfully euthanized with a single application of the CASH Dispatch captive bolt device displayed haemorrhage in all 5 neuroanatomical regions assessed (cerebral cortex, cerebellum, thalamus, pons and medulla). However, 2 of the 4 pigs requiring a secondary euthanasia step lacked haemorrhage in the medulla and pons. Interestingly, although all pigs successfully euthanized with a single shot of the penetrating captive bolt displayed traumatic brain injury in the cerebral cortex, only 1 pig (weight class 4) showed traumatic brain injury in any of the other 4 regions of the brain. Two of the 4 pigs requiring a second shot displayed no evidence of direct penetration to any region of the brain, but 2 pigs showed traumatic brain injury in the cerebral cortex. Hence, macroscopic assessment of traumatic brain injury failed to identify neuroanatomical regions of the brain associated with effective penetrating captive bolt euthanasia. All pigs euthanized with the non-penetrating captive bolt displayed injury and haemorrhage in all 5 neuroanatomical regions.

Identification of bolt trajectory based on radiographs was not found to be a reliable technique. Trajectory was most important for the mature weight classes of pig (6 and 7), where variability in response was observed. However, radiographs were not sufficiently robust for identification of the skull fragment amidst the dense skull and sinus in these weight classes.

Experiment 2: Evaluation of a captive bolt device, the CASH Dispatch Captive Bolt Gun, as a single step euthanasia method in a commercial production setting

A total of 210 pigs were euthanized in this experiment. One pig in weight class 1 was removed from the trial due to a suspected faulty cartridge during euthanasia, for a total of 209 pigs included in the data analysis. There were 202 pigs (97%) that were effectively euthanized with a single application of the "Cash" Dispatch Kit. Seven pigs (2 sows and 5 boars) in weight classes 6 and 7 required a second shot (Table 5). Weight class was significantly associated with the need for a second shot ($P=0.006$). Stockperson was also associated with the need for a second shot ($p=0.0048$), but there were no differences between sows and boars. Two-thirds of the pigs (4 of 6 pigs) that required a second shot vocalized (Table 6, $p=0.0038$). Similarly, two-thirds of pigs that required a second shot displayed respiration after the initial shot ($p=0.00002$). However, vocalization and respiration were also observed in pigs that were successfully euthanized, indicating that neither is a reliable predictor of euthanasia success.

Time to last movement and cessation of cardiac function both occurred approximately 3 minutes after the application of the Cash Dispatch captive bolt device. Time to last movement was associated with weight class (Figure 4, $p=0.0001$), but not with sex. Movements were variable and often quite violent. On average, pigs performed 117 kicks (+/- 4) of a single hindlimb, with the greatest variation observed in the heaviest weight class, ranging from 14 to 361 kicks (Figure 5). Number of kicks was not associated with weight class or sex.

Time to last heartbeat was associated with weight class (p=0.012), but not sex. Weight accounted for 7.9% of the variability in heartbeat (Figure 6).

DISCUSSION

One of our objectives was to determine effectiveness of a single application of the captive bolt device for euthanasia of pigs at different ages. Based on expected slaughter standards published by the American Meat Institute (AMI, 2010), insensibility must be achieved 95% of the time when using a captive bolt gun in order to obtain a passing score on the animal welfare audit. In Experiment 1, the Cash Dispatch Kit successfully euthanized 100% of the anesthetized pigs in the 5 lowest weight classes with a single application. However, 8 of the 12 (66%) pigs in the mature weight classes (200+ kg) required a secondary method. The manufacturers adjusted the device following the results from Experiment 1, in terms of increasing the cartridges for mature animals, and decreasing the charge for the smallest weight class. In Experiment 2, 97% of all pigs were successfully euthanized with a single application of the modified Cash Dispatch device, and again variability occurred in the mature weight classes (>200kg) in which 10% of the animals required a second shot. In the on-farm study, application of a second shot was sufficient to ensure euthanasia, and can be an alternative to exsanguination or pithing.

Involuntary movements were observed for approximately 3 minutes following application of the captive bolt device, and occurred in bouts of clonic activity (paddling). The duration of movement observed in this study may have been affected by handling, since our palpation to obtain pulse may have stimulated afferent nerve impulses to the spine and provoked spinal reflexes no longer inhibited by the (damaged) brain stem. Although on average cardiac function also appeared to cease after approximately 3 minutes, your measurements were likely not sufficiently sensitive to detect a faint and fluttering pulse during the dying process, especially with large pigs.

There was considerable variation in response between individuals for most of the outcome variables measured, including duration and intensity of movement, latency to cease cardiac function, vocalizations and respiration. Interestingly, although associated with the need for a second shot, occurrence of vocalization and respiration were not reliable indicators of unsuccessful euthanasia since these were performed by individuals who were successfully euthanized, albeit less often. It is also interesting that successful euthanasia occurred even in the absence of macroscopic evidence of traumatic brain injury. For penetrating captive bolt euthanasia, concussive forces and associated haemorrhage appear to be more relevant than direct brain injury caused by bolt or skull fragment penetration.

There were associations between stockperson and a number of outcome variables, including the need for a second shot. However, stockperson was confounded with weight class, since individuals worked in particular stages of production, and hence further research is needed to clearly understand this factor. Our casual observation suggests that landmarks on the pig head were usually correctly identified, but ensuring that the pistol was flush against the head at a correct angle was likely to affect efficacy. Restraint of the head through snaring appeared to be important for both efficacy and safety, rather than restraint in a chute or stall.

We conclude that the Cash Dispatch captive bolt device is effective as a single step euthanasia method for pigs <200kg. For mature animals, further refinements in terms of equipment design and/or application by stockpeople are needed to ensure reliable performance with mature animals. Stockpeople should be prepared to administer a second shot swiftly when euthanizing mature pigs with a captive bolt device.

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Table 1. Cash Dispatch Kit captive bolt bolt types and stem diameters and lengths (Accles and Schevolke, Sutton Coldfield, West Midlands, UK).

Muzzle type	Bolt Diameter (cm)	Stem Length (cm)
Non-Penetrating	3.8	N/A[a]
Short Bolt	1.2	12.2
Medium Bolt	1.2	15.5
Extended Bolt	1.2	17.4

[a] The non-penetrating head does not have a stem that extends from the muzzle and penetrates the skull.

Table 2. Coordination of muzzle type and power load to weight class of pig for the Cash Dispatch Kit captive bolt device.

Pig Weight Class	Muzzle Type	Cartridge Color [a]	Nominal Propellant Charge[b]
1 (2 - 3 kg)	Non-penetrating	Pink	135 mg
2 (7.5 - 10 kg)	Non-penetrating	Pink	135 mg
3 (15 - 20 kg)	Short Bolt	Yellow	160 mg
4 (30 - 40 kg)	Short Bolt	Yellow	160 mg
5 (100 - 120 kg)	Medium Bolt	Blue	210 mg
6 (200-250 kg)	Extended Bolt	Orange	265 mg
7 (>300 kg)	Extended Bolt	Black[c]	295 mg[c]

[a] The tip of each cartridge is painted with the coordinating color of the nominal propellant charge for easy identification by users. (Accles and Schevolke, Sutton Coldfield, West Midlands, UK)

[b] The minimal force produced by expanding gas that propels the bolt out of the gun upon firing.

[c]For study 1, Orange cartridges were used for all mature pigs. Based on variable results from study 1, more powerful Black cartridges were used for very large mature pigs (Weight Class 7) during study 2.

Table 3. Descriptive information for anesthetized pigs that required electrocution as a secondary method of euthanasia following a single administration of the Cash Dispatch captive bolt device.

Ear Tag	Weight Class	Sex	Face shape	Eye blink response[a]	Vocal sounds[b]	Rhythmic breathing[e]	Clonic movements[d]	Heartbeat at 10 min[e]
13	6	M	Dish face	Yes	No	Yes	Yes	Yes
17	6	M	Dish face	Yes	No	Yes	No	No
16	7	M	Intermediate	Yes	No	Yes	No	No
24	7	F	Plank face	No	Yes	Yes	Yes	Yes

[a] Light touching of the cornea with a finger to detect the presence of involuntary blinking.

[b] Orally or nasally audible noises including gasps, groans or grunts. Sow #24 made 80 audible noises described as "snoring" sounds.

[c] Observed visually and acoustically.

[d] Repeated muscular spasms (i.e. kicking).

[e] Palpated directly behind the forearm, and latency for cessation of heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heart rate.

Table 4. Time to last heartbeat (seconds) for different weight classes of anesthetized pig that were successfully euthanized with a single application of the Cash Dispatch captive bolt device ($p=0.0071$, $R^2=0.16$). The presence of a detectable heartbeat was palpated and latency for cessation of heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heart rate.

Weight Class	No. Pigs	Median	1st, 3rd Quartiles	Minimum, Maximum
1 (2 to 3 kg)	(n=6)	367	312, 416	0, 451
2 (7.5 to 10 kg)	(n=6)	296	244, 340	174, 357
3 (15 to 20 kg)	(n=6)	276	251, 292	144, 352
4 (30 to 40 kg)	(n=6)	293	180, 335	0, 350
5 (100 to 120 kg)	(n=6)	204	149, 264	135, 380
6 (200-250 kg)	(n=4)	193	109, 266	1, 343
7 (>300 kg)	(n=4)	125	0, 111	0, 151

Table 5. Descriptive statistics for 7 pigs that required a second shot for on-farm euthanasia using the Cash Dispatch captive bolt device.

Sex	Weight Class	Stockperson[a]	Respiration[b]	Eyeblink Response[c]	Animal Snared	Correct Targeting [d]
M	6	A	Yes	Yes	No	No
F	6	B	Yes	No	Yes	Yes
M	7	A	Yes	No	No	No
M	7	A	Yes	Yes	No	No
M	7	A	Yes	Yes	No	No
M	7	C	Yes	Yes	No	Yes
F	7	B	No	No	Yes	No

[a] Stockpersons were identified by the number assigned to their site (first digit) and the stockperson number they were assigned (second digit).

[b] If respiration was visible or audible following first application of captive bolt gun.

[c] Light touching of the cornea with a finger to detect the presence of blinking reflex.

[d] Correct placement based on landmark, angle and flush contact of the muzzle to the skull was subjectively assessed visually by one researcher (JW).

Table 6. Association between the need for a second shot and number of vocalizations following a single application of the Cash Dispatch captive bolt device (p=0.0038). Frequency percent 0 refers to pigs that were successfully euthanized with a single shot (n=203), and 1 refers to pigs that required a second shot (n=6).

Second shot	Vocalizations															
Frequency Percent	0	1	2	3	6	7	10	12	13	14	15	17	21	24	34	Total
0	177 84.7	7 3.4	3 1.4	4 1.9	1 0.5	2 1.0	1 0.5	0 0.0	2 1.0	1 0.5	1 0.5	1 0.5	1 0.5	1 0.5	1 0.5	203 97.1
1	2 1.0	1 0.5	0 0.0	1 0.5	0 0.0	0 0.0	0 0.0	1 0.5	0 0.0	0 0.0	1 0.5	0 0.0	0 0.0	0 0.0	0 0.0	6 2.9
Total	179 85.7	8 3.8	3 1.4	5 2.4	1 0.5	2 1.0	1 0.5	1 0.5	2 1.0	1 0.5	2 1.0	1 0.5	1 0.5	1 0.5	1 0.5	209 100.0

Figure 1: Cash Dispatch Kit, including 4 bolt types for different weight categories of pig (Accles and Schevolke, Sutton Coldfield, West Midlands, UK).

Figure 2. Cross section of the skull from mature sow successfully euthanized with a single shot from the Cash Dispatch captive bolt device. The knife shows the trajectory of the bolt through the sinus, with bone fragments projected into the frontal cortex. Note haemorrhage present in the brain stem (arrow), due to indirect injury associated with concussive forces.

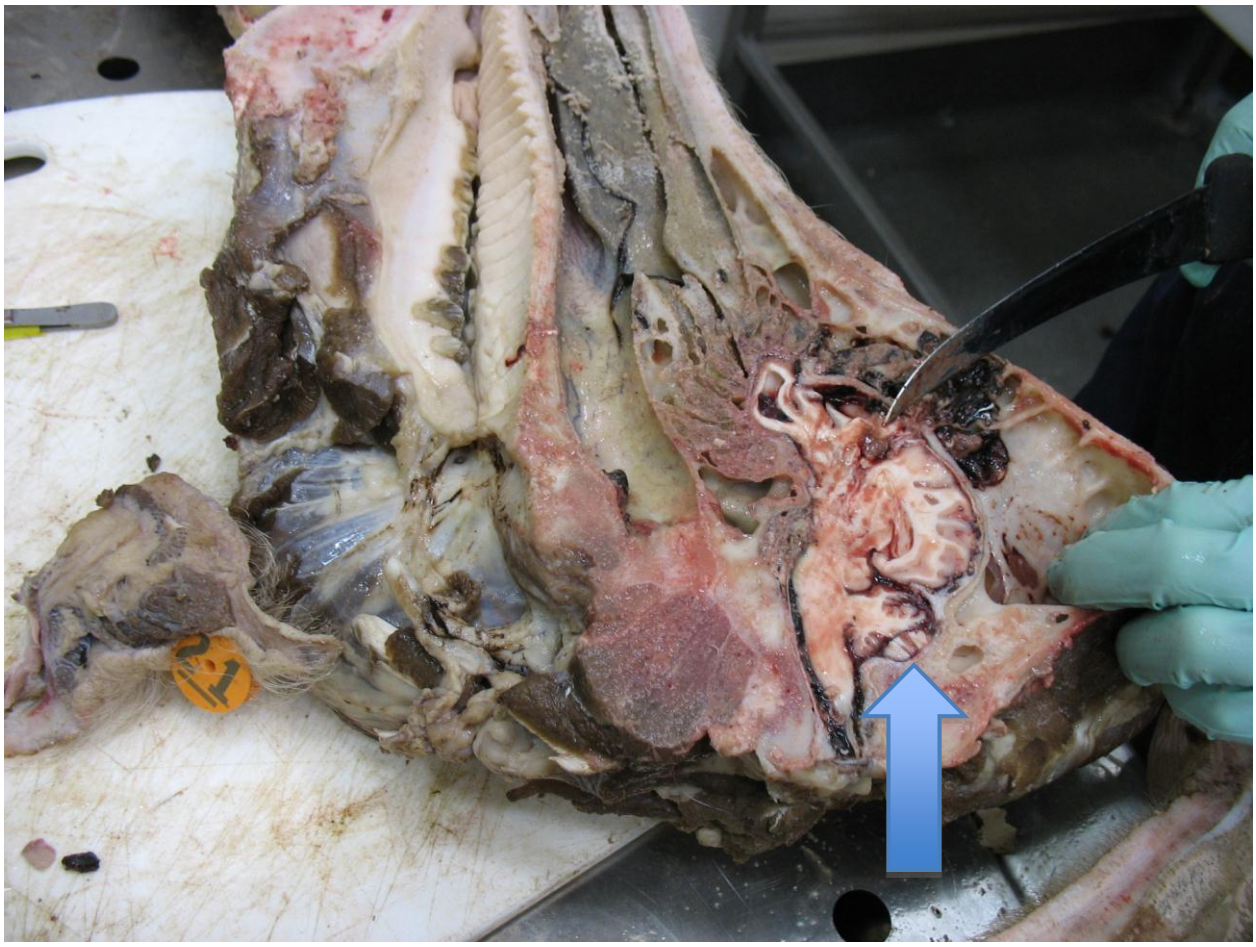

Figure 3. Time to last movement (seconds) for different weight classes of anesthetized pig that were successfully euthanized with a single application of the Cash Dispatch captive bolt device (p=0.59). Note high variability in response for the heaviest weight classes of pig. Weight classes: 1=2-3kg, 2=7.5-10 kg, 3=15-20 kg, 4=30-40 kg, 5=100-120 kg, 6=200-250 kg and 7=>300 kg

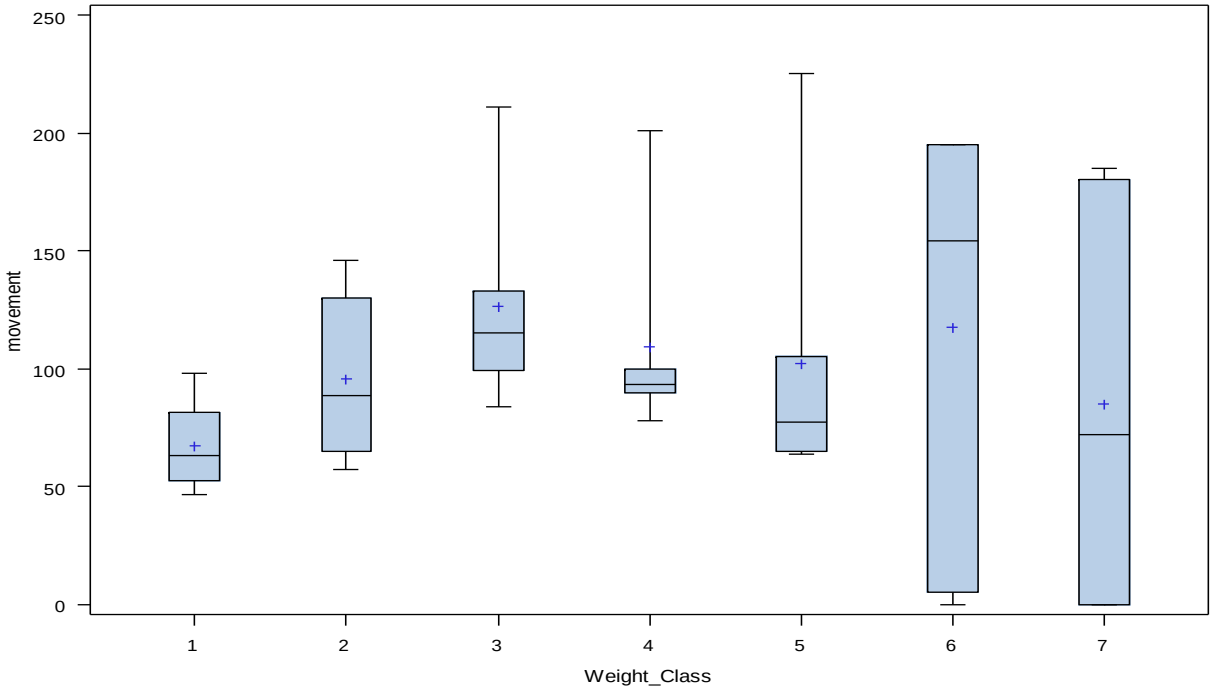

Figure 4. Time to last movement (seconds) for 7 weight classes of pigs that were successfully euthanized on-farm with a single application of the Cash Dispatch captive bolt device (p=0.0001). Latency for cessation of movement including twitching of the tail or snout and was determined using a stopwatch.

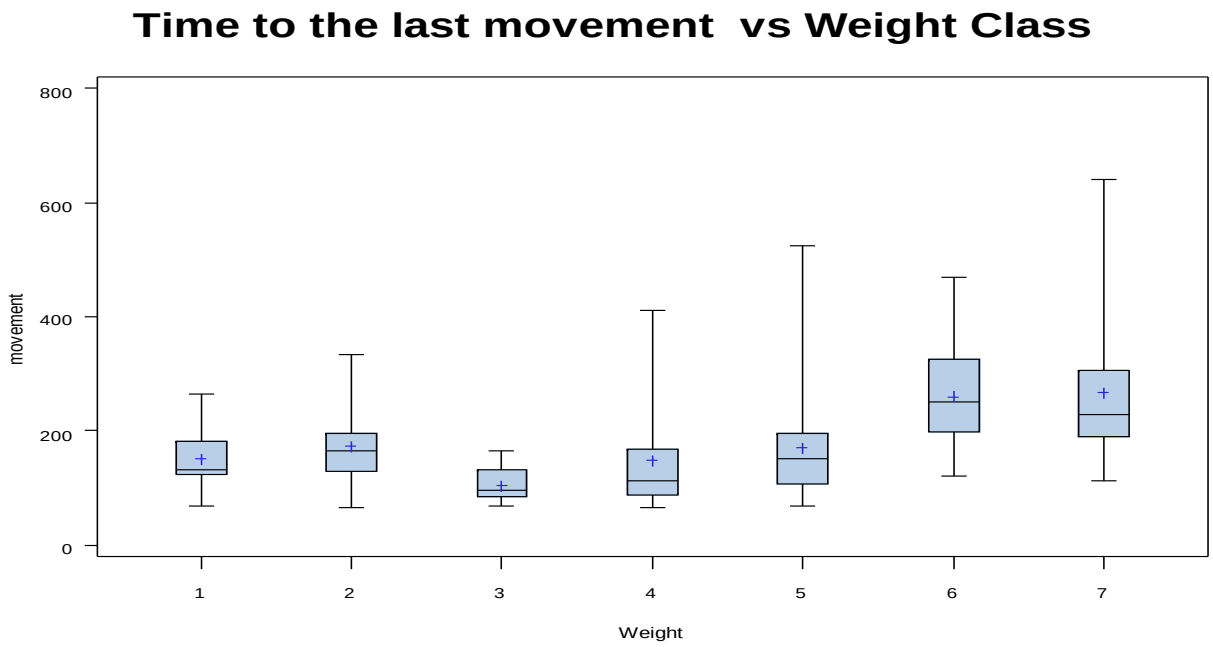

Figure 5. Average number of kicks for the 7 weight classes of pigs euthanized successfully on-farm with a single application of the Cash Dispatch captive bolt device. The number of kicks was counted on one hind leg and tallied with a hand counter (p=0.26).

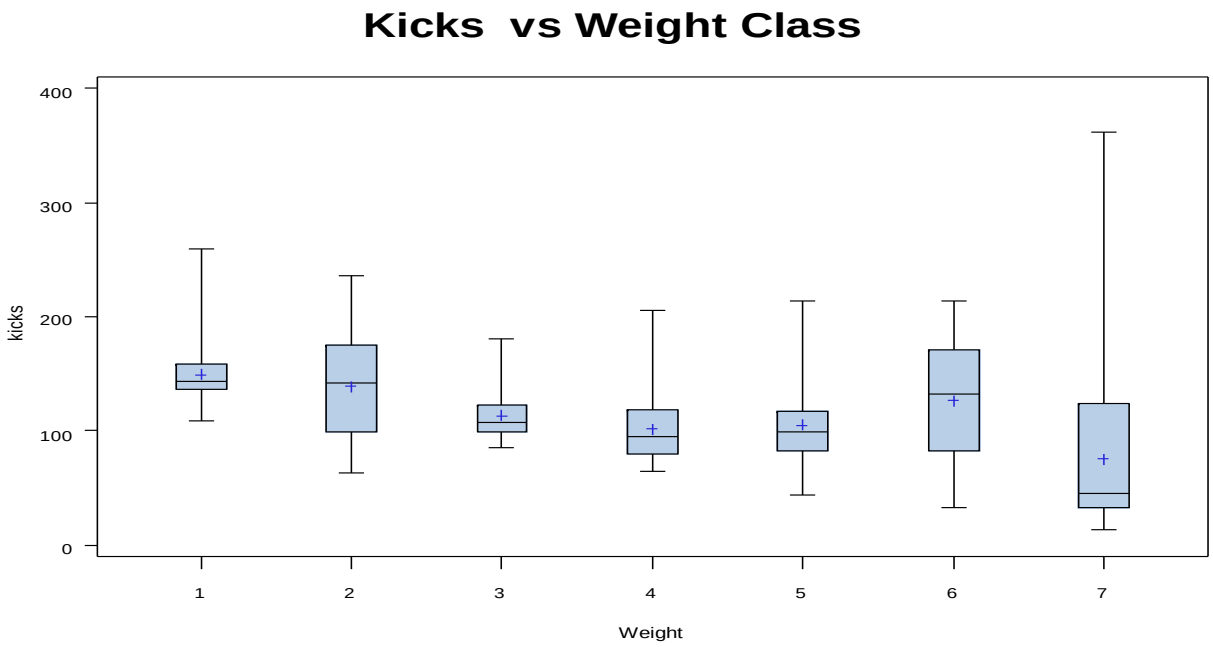

Figure 6. Box plot showing distribution of time to last heartbeat (seconds) for different weight classes of pig that were successfully euthanized on-farm with a single application of the Cash Dispatch captive bolt device (p=0.012). Note high variability in response for the heaviest weight classes of pig. Weight classes: 1=2-3kg, 2=7.5-10 kg, 3=15-20 kg, 4=30-40 kg, 5=100-120 kg, 6=200-250 kg and 7=>300 kg