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Evaluation of potential killing performance of novel percussive and cervical dislocation tools in chicken cadavers

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Short title: Novel percussive and cervical dislocation tools for despatching poultry

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Abstract

1. Four mechanical poultry killing devices; modified Armadillo® (MARM), modified Rabbit Zinger™ (MZIN), modified pliers (MPLI) and a novel mechanical cervical dislocation gloved device (NMCD), were assessed for their killing potential in cadaver chickens (four bird type and age combinations: layer/adult, layer/pullet, broiler/slaughter-age, broiler/chick).
2. A 4x4x4 factorial design (batch x device x bird type + age) was employed. Ten birds per bird type (+ age) were tested with each of the four mechanical devices (N = 160 birds). All birds were examined post-mortem in order to establish the anatomical damage sustained to the bird by the device.
3. Three of the mechanical methods: NMCD, MARM and MZIN demonstrated killing potential, as well as consistency in physiological effects, with device success rates of over 50%, indicating that more than half the time the devices performed optimally. NMCD had the highest kill potential, with 100% of birds sustaining the required physiological trauma to have caused rapid death.
4. The MPLI did not show consistency, and only performed optimally for 27.5% of birds, despite matching killing potential with the MARM. Severe crushing injury was seen in >50% of MPLI birds, suggesting birds would die of asphyxia rather than cerebral ischemia, a major welfare concern. As a result the MPLI are not recommended as a humane on-farm killing device for chickens.
5. The results of this experiment provide important data on the evaluation of the killing potential of untried novel percussive and mechanical cervical dislocation methods on chicken cadavers.

Keywords

Killing; poultry; cervical dislocation; percussive; post-mortem; animal welfare.

Introduction

Worldwide, an estimated 9.1 billion birds may need to be killed on farm each year (DEFRA 2015) and the method in which these birds are killed is crucial to poultry welfare on a large scale. Poultry may need to be killed on-farm for multiple reasons (e.g. injury, sickness and for stock management). Emergency killing on a large scale is often controlled by whole-house or containerised gas methods (e.g. Lambooij *et al.*, 1999; Gerritzen *et al.,* 2004; Gerritzen *et al.,* 2009; McKeegan *et al.,* 2011). For individual birds on-farm, there are two main methods for killing poultry: (i) cervical dislocation, which is designed to cause death by cerebral ischaemia and extensive damage to the spinal cord and brainstem (Ommaya & Gennarelli 1974; Gregory & Wotton 1990; Erasmus *et al*., 2010a,b; Bader *et al*., 2014; Martin *et al*., 2016); and (ii) percussive devices designed to cause extensive brain damage, resulting in brain death (Gregory & Wotton, 1990; HSA, 2004; Mason *et al.,* 2009; Erasmus *et al*., 2010a,b; Sparrey *et al*., 2014; Cors *et al.,* 2015).

Cervical dislocation has been shown to be one of the most prevalent methods for killing individual birds and is used in commercial and non-commercial contexts, as it is perceived to be humane by users, easy to learn and perform, and does not require equipment (Mason *et al*., 2009; Sparrey *et al.,* 2014; Martin, 2015; Martin *et al.*, 2016). Both manual and mechanical cervical dislocation killing methods are designed to separate the skull from the vertebral column of the bird (C0–C1 vertebral dislocation), resulting in severing of the spinal cord and/or brainstem and the main blood vessels supplying the brain (Gregory & Wotton, 1990; Parent *et al*., 1992; Veras *et al*., 2000; Cartner *et al.,* 2007; Mason *et al.,* 2009). It has been suggested that optimal application also produces a concussive effect on the bird due to trauma inflicted on the brainstem through the action of stretching and twisting (Harrop *et al.,* 2001; Shi & Pryor, 2002; Pryor & Shi, 2006; Shi & Whitebone, 2006; Cartner *et al*., 2007; Erasmus *et al*., 2010a). However, both methods of cervical dislocation have been the subject of welfare concern, as research in the last 40 years has questioned their humaneness and consistency in poultry (Gregory& Wotton, 1986, 1990; Erasmus *et al*., 2010a), as well as other species (Tidswell *et al*., 1987; Cartner *et al*., 2007). Some studies have indicated that animals, including poultry, may be conscious for a significant period post-application of cervical dislocation methods (Gregory & Wotton, 1990; Erasmus *et al*., 2010a; Carbone *et al*., 2012) and it has been noted that there is high variability in its application by different relevant groups (e.g. poultry stock-workers, veterinarians, trained slaughtermen) (Mason *et al.,* 2009; Sparrey *et al.,* 2014). As of January 2013 the use of manual cervical dislocation (MCD) as a killing method for poultry on-farm has been heavily restricted through the new EU legislation, Regulation (EC) no. 1099/2009 On the Protection of Animals at the Time of Killing (European Commission, 2009), following reported welfare concerns. FAWC (2009) recommended research to explore current and novel methods for killing poultry in small numbers. Several mechanical devices have been developed recently (e.g. CASH Poultry Killer, Turkey Euthanasia Device) (Erasmus *et al*., 2010a; Erasmus *et al*., 2010b; HSA, 2004; Raj and O'Callaghan, 2001), however, none have been enthusiastically adopted across the commercial industry or by small poultry keepers.

Previous research has shown that post-mortem analysis is effective in inferring killing potential and time to loss of consciousness and has been used across several species in determining success rates of slaughter and on-farm killing method in livestock species (e.g. Anil *et al.*, 2002; Grandin, 2010; Morzel *et al*., 2002; Bader *et al.*, 2014). For example the successful application of cervical dislocation methods is determined by the animal having its neck dislocated and the spinal cord severed (Bader *et al*., 2014; Carbone *et al*., 2012; *Cartner et al.*, 2007; Erasmus *et al.,* 2010a), while for concussive (head trauma) devices, there must be sufficient damage (e.g. skull fractures, brain contusions, cerebral oedema, hemorrhaging and *contra-coup* damage) (Finnie *et al.,* 2000; Finnie *et al.,* 2002; Gregory *et al.,* 2007; Gregory and Shaw, 2000). Determining the success rate of a killing device is essential to evaluating its overall efficacy. The designing and prototyping of novel and modified devices is the first stage in tool development and a hopeful provision of a new humane device to despatch poultry on-farm. This study assesses the potential kill performance of four novel or modified mechanical devices on both layer and broiler cadavers, through post-mortem analysis to establish whether the devices should be taken forward and evaluated in live and conscious birds as potential new on-farm killing methods for chickens.

Methods

Subjects and husbandry

A total of 160 female layer-type (Hy-Line) and meat-type (Ross 308) chickens (*Gallus gallus domesticus)* were used for the study across four batches and distributed equally across two types and ages (Table 1). Birds were sourced from commercial farms and transported to SRUC facilities in four batches of 40 birds per batch, with each batch containing all four bird type and age combinations. All birds were weighed and wing-tagged on arrival.

The birds were housed for one week prior to the experiment in order to allow them to acclimatise to the new environment. Birds were housed in separate rooms per bird type and age group to provide recommended environmental controls (Aviagen, 2009; Hy-Line, 2012). All birds were kept in floor pens with wood-shavings litter at significantly lower than commercial stocking density and with various environmental enrichments (e.g. suspended CDs, perches) (DEFRA, 2002a; DEFRA, 2002b). All pens were constructed from wooden frames with wire-grid sides and roofs, allowing visual and auditory contact with other birds within the same room. Broiler chicks and layer pullets were housed in group pens (L 1.5 m x W 2.5 m x H 1.5 m). Broilers (slaughter-age) and layer hens were kept in pairs. Pen sizes were L 1.5 m x W 0.5 m x H 1.5 m. All birds had *ad libitum* access to appropriate food and water. All birds were inspected twice daily, and the minimum and maximum temperatures were recorded each morning.

This experiment was performed under UK Home Office licence authority via Project and Personal licences and underwent review and approval (AUAE8-2012) by SRUC's ethical review body. All routine animal management procedures were adhered to by trained staff.

Experimental Procedure

Four mechanical poultry killing devices: modified Armadillo® (MARM), modified Rabbit ZingerTM (MZIN), modified pliers (MPLI) and a novel mechanical cervical dislocation gloved device (NMCD) were assessed for their killing potential in cadaver birds (four bird type and age combinations). All methods developed are discussed in detail in Martin, 2015 and were designed to comply with the current European legislation, EC1099/2009 (European Council, 2009). Briefly, the Armadillo® (shown in Figure 1a) is a brain-stem penetrating device designed by a veterinarian (John Dalton) to dispatch game birds in the field (Sparrey *et al.,* 2014; Martin, 2015). The device is a scissor-type mechanism (approximately 17 cm in length), in which the bird's head is placed into the 'cup' of the lower arm (beak facing downwards) and when ready to apply the operator squeezes the handles together, which pushes the top arm (and the penetrating spike) downwards into the back of the bird's skull, preferably through the foramen magnum therefore severing the top of the spinal cord (or brain stem), and causing death by cerebral ischemia. Presently there is no published scientific evidence on the efficacy of this device. Modifications (with permission of inventor) consisted of replacing the lower arm of the device in order to increase the upper (U) (33 mm to 37 mm) and lower (L) (19 mm to 27 mm) diameters of the openings of the metal cup based on pilot work demonstrating the need for a more space to encompass chicken heads. Additional insertion cups were molded from 1mm thick plastic funnels, in order to generate two adjustments (G1, G2) to fit the various sizes of birds' heads, based on bird type and age (G1: U=36 mm and L=23 mm (broiler, layer hen); G2: U=30 mm and L=18 mm (layer pullets, broiler chicks)). The additional cups also had soft padding (Waxman 4719095N ½ inch Self Stick Felt Pads, Waxman, Ohio, United States) added to their sides, which cushioned the lateral sides of the bird's head (over the eyes) as well as creating an oval shape for the upper opening.

The Rabbit Zinger™ (Pizzurro, 2009a,b) is a penetrating captive-bolt device originally designed to kill rabbits (shown in Figure 1b). It uses the stored energy in rubber tubes to drive a penetrating bolt into the animal's head, causing death by extensive irreversible brain damage (DEFRA 2014; Martin 2015). The device was modified with permission of the original designer in order to adapt it to the new target species (i.e. poultry), however the original function and bolt mechanism of the device was retained. The blue Power Tubes™ (Pizzurro, 2009a) were used, which require 177 N to pull the bolt into the cocked position (Sparrey *et al*., 2014; Martin *et al.,* 2016) and when fired the bolt (0.6 mm diameter) delivered approximately 11.87 J of kinetic energy. The modifications have been described previously (Martin, 2015; Martin *et al.,* 2016), but briefly consisted of three aluminium appendages added to the base of the device in order to provide a method of gently restraining the bird's head: two rested either side of the bird's head (over the ears, orauricular feathers) and the third ran down the front of the bird's face between the eyes and over the nostrils and beak. Additional leather washers (Pizzurro, 2009a,b) were added to the bolt, in order to reduce the penetration depth from 3.5 to 2.5 cm. The MZIN device was also weighted at the bottom in order to counteract the top-heaviness of the device when cocked.

Cervical dislocation pliers have been reported as popular amongst the poultry industry (Sparrey *et al.,* 2014; Martin, 2015), however, research has demonstrated they do not cause an immediate loss of consciousness (e.g. loss of Visual Evoked Responses (VERs) as a possible indicator of loss of consciousness (Gregory and Wotton, 1990)), and in the 'Semark' pliers have a low success rate in fully dislocating the neck and severing the spinal cord (Gregory and Wotton, 1990) and are suggested to cause crushing injury (DEFRA, 2014). 'Semark' pliers (also known as the 'Humane Bird Dispatcher') weigh approximately 200 g and have an overall length of 180 mm. When the blades of the device are fully open the maximum distance between the upper and lower teeth is 36 mm. When the blades are fully closed there is a slight gap between the blades (<1 mm). The pliers were modified (MPLI) in an attempt to reduce crushing injury by adapting the shape and width of the blades in order to create a narrower, curved concave edge rather than a straight edge (Martin, 2015). The edges of the blades remained blunt in order to reduce the risk of skin tearing and thus blood loss during application of the method. It was hypothesised that by narrowing the edge of the blade it would reduce the risk of crushing and would instead increase the likelihood of dislocation, as the narrower blade would more easily slip between two cervical vertebra when force was applied. The blades were widened gradually to increase the size of the blade (over 3 mm) and therefore generate a dislocation (i.e. gap between the two vertebra), through pushing the vertebrae apart.

The NMCD device (Figure 1d) was designed to create a mechanical method for cervical dislocation of poultry which mirrored the technique of the manual method (described in Martin, 2015; Martin et al., 2016). The device consisted of a thin supportive glove (SHOWA 370 Multipurpose Stable Glove™, UK) designed to support the wrist and hand (and therefore hypothesised to reduce strain injury in the operator) and a moveable metal insert. The metal insert was made up of two metal finger supports and were designed to fit around the bird's head to create a secure grip, and to move independently from side-to-side in order to allow adjustment for different sizes of birds (Figure 1d). The rounded shape of the metal fingers was designed to aid the twisting motion (performed during manual cervical dislocation (Sparrey *et al.*, 2014; Martin *et al.*, 2016)) required to dislocate the bird's neck by enhancing the 'rolling action' of the hand. The blunt edge between the two metal fingers (protruding < 1 mm from the fleshy area of skin between the index and middle fingers) provided a hard edge to force between the back of the bird's head and the top of the neck, designed to focalise the force into the desired area (i.e. a dislocation at C0–C1) when the method was applied.

The experiment was designed around a 4 x 4 x 4 factorial design (batch x device x bird type + age). Ten birds per bird type (+ age) were tested with each of the four mechanical devices (N = 160 birds). Birds were tested in four one week batches, with birds being tested in blocks of ten per day in order to minimise any effect of operator fatigue (Sparrey *et al*., 2014). A Graeco Latin square was used to balance batch, block, bird type (+ age) and device. Within this, 4 Latin squares (1 per batch) were used to balance block, test order in block and bird type (+age), with the test order in each block then repeated until all 10 birds were tested.

All birds were weighed and had schematic measurements of the head and neck were taken (Figure 2). Because it would have been inappropriate to have evaluated un-tested killing methods on live birds, the birds were sequentially humanely euthanised by an intravenous sodium pentobarbital injection (Euthatal, Merial Animal Health Ltd., Essex, UK) into the brachial vein immediately prior to device testing in order to minimise blood coagulation and morphological changes (Gordon *et al*., 1988; Bell *et al.,* 1999).

After device application, the cadavers were immediately examined post-mortem in order to establish as accurately as possible the anatomical damage sustained to the bird by the device. Specific post-mortem measures were recorded for each killing device as their target anatomical areas were different. For all killing devices binary measures were recorded for skin broken, external blood loss and subcutaneous hematoma and the total number of attempts were recorded (e.g. multiple pulls for NMCD or miss-fire of MZIN). For the MZIN and MARM, seven specific measures were recorded: binary measures of damage to the skull, specific brain regions (left forebrain, right forebrain, cerebellum, midbrain and brainstem); and the presence of an internal brain cavity hematoma. For killing devices which caused trauma to the neck of the bird (NMCD and MPLI), seven specific post-mortem measures were assessed: four binary measures were recorded for dislocation of the neck, vertebra damage (e.g. intra-vertebra dislocation/break), damage to neck muscle, crushing injury to the trachea or oesophagus and whether the spinal cord was severed. The level of cervical dislocation was recorded (e.g. between C0-C1, C1-C2, C2-C3, etc.), as well as a measurement of the length (cm) of the gap between the dislocated cervical vertebra. The number of carotid arteries severed was also recorded as zero, one or both.

Derived kill potential and device success

From the post-mortem evaluations two binary (yes/no) measures were derived: kill potential and device success. Kill potential was defined as the cadaver exhibiting sufficient damage to any part of the anatomy which would have resulted in death (if the bird had been alive at testing) following one attempt. For example, this was confirmed dislocation of the neck and severing of the spinal cord for NMCD and MPLI (Bader et al., 2014; Erasmus et al., 2010a; Gregory and Wotton, 1990); and diffuse brain damage for the MARM and MZIN (Finnie *et al*., 2000; Finnie *et al.,* 2002; Limon *et al*., 2010) after one attempt.

Device success was defined as when the device caused the desired anatomical damage, dictated by its hypothesised design, as well as producing sufficient damage which would have resulted in death (if the bird had been alive at testing) and based on scientific literature would be most likely to minimise time to unconsciousness post device application. Device success criteria were device specific and are described in Table 2.

Statistical Analysis

All data were summarised in Microsoft Excel (2010) spread sheets and analysed using Genstat (14th Edition). Statistical significance was based on F statistics and P<0.05 significance level. Summary graphs and statistics were produced at bird and treatment level. Generalised Linear Mixed Models (GLMM) (binomial distribution) were used to compare performance across the four killing devices in terms of kill potential and device success, while incorporating bird type, age, and block as fixed effects and bird weight head measurements as co-variates. Batch was included as a random effect. Detailed comparisons of device performance were achieved by sub setting the data twice: initially to remove unsuccessfully “killed” birds (i.e. kill potential “no”) in order to prevent data skewing; and then into two groups dependent on trauma area: 1) neck trauma (NMCD and MPLI); and (2) head trauma (MZIN and MARM), in order to allow logical comparison between killing treatments which damaged the neck or the head. Statistical comparisons on anatomical measures were conducted via GLMMs (Poisson distribution and binomial distribution) or Linear Mixed Models (LLM) (normal distribution) dependent on the data distributions for each variable. Data transformations were attempted when necessary via Logarithm function. All models included batch number as random effects. All fixed effects were treated as factors and classed as categorical classifications and all interactions between factors were included in maximal models.

Results

A total of 36 birds were not successfully “killed” on the first attempt (NMCD = 0/40 birds; MPLI = 15/40 birds; MARM = 15/40 birds; and MZIN = 6/40 birds). Device had an effect on kill potential ($F_{(3,144)}$=2.88, P=0.038), with NMCD having the highest kill potential, with 100% of birds sustaining the required physiological trauma to have caused death (Figure 3). The MARM and MPLI had the lowest kill potential, with both achieving 62.5%. Bird age was the only other factor to affect kill potential ($F_{(1,144)}$=5.15, P=0.025), with younger birds being more likely to sustain the required physiological trauma to have resulted in death (mean = 0.87 ± 0.04), compared to older birds (mean = 0.68 ± 0.05). All other factors (e.g. bird weight, type) and their interactions had no effect on kill potential.

Device success was significantly affected by killing device ($F_{(3,144)}$=7.00, P<0.001), with NMCD shown to be most likely to perform in the desired way and producing optimal damage to the birds (Figure 3). Like kill potential, bird age significantly affected device success ($F_{(1,144)}$=5.03, P=0.026), with younger birds (mean = 0.69 ± 0.05) being more likely to sustain optimal physiological damage compared to older birds (mean = 0.53 ± 0.06). All other factors and their interactions had no effect on device success.

Percussive methods

For successfully killed birds (MARM = 25/40 birds; and MZIN = 34/40 birds), the percentage of birds for which the relevant head trauma post mortem factor was present, according to killing method is shown in Table 3. Killing device had no effect on the majority of post-mortem measures, apart from damage to left forebrain, mid brain, and brain stem. The MZIN was significantly more likely to cause trauma to the left forebrain and the mid brain compared to the MARM, however, the opposite was seen for the brain stem, with very few birds receiving the MZIN method sustaining damage compared to the MARM. No other factor or interaction had an effect on external bleeding, skin tearing, subcutaneous hematoma, and whether or not the skull was damaged. Bird type, bird age, bird weight and their interactions with killing method had no effect on damage to any region of the brain.

Cervical dislocation methods

For successfully killed birds (MPLI = 25/40 birds; NMCD = 40/40 birds), the percentage of birds for which the relevant neck trauma post mortem factor was present, according to killing method, is shown in Table 4. MPLI was more likely to tear the skin, cause external bleeding, vertebral damage, trachea damage, and oesophagus damage compared to NMCD, although the differences were not significant. NMCD was significantly more likely to cause cervical dislocation, as well as severing one or more carotid arteries compared to MPLI (Figure 4). However, the location of the dislocation (e.g. C0-C1, C1-C2, etc.) was not significantly affected by killing method ($F_{3,74}$=2.34, P=0.076), although it had a tendency ($P < 0.10$), with NMCD to be more likely to cause a higher level dislocation (e.g. C0-C1) compared to MPLI (Figure 5).

Whether or not cervical dislocation (no = 0; yes = 1) occurred was significantly affected by bird type ($F_{1,74}$=5.98, P=0.014) and bird age ($F_{1,74}$=6.39, P=0.011), with dislocations more likely to occur in broilers (mean = 0.95 ± 0.05) rather than layers (mean = 0.55 ± 0.11), and younger birds (mean = 0.90 ± 0.07) compared to older birds (mean = 0.60 ± 0.11). The diameter of the birds' necks (N1) ($F_{1,74}$=4.00, P=0.050) was also shown to have an effect with unsuccessful dislocations associated with larger neck diameters (17.1±1.09 mm) compared to successful dislocations (14.9±0.51 mm). Bird type had an effect on the likelihood of vertebral damage (no = 0; yes = 1), with layers (mean = 0.75 ± 0.10) more likely to sustain damage than broilers (mean = 0.35 ± 0.11). No other factors or interactions, apart from killing method (reported above) had an effect on vertebral damage.

Bird type, bird age, and bird weight and their interactions with killing device had no effect on skin tearing, external bleeding, subcutaneous, hematoma, trachea damage, oesophagus damage, number of carotid arteries severed, dislocation level, and dislocation level. The neck diameter of the birds (N1) had a tendency to affect the number of carotid arteries severed ($F_{1,74}$=3.31, P=0.074), with a significant negative correlation (r = -0.382, P = 0.047) between these.

Discussion

The results of this experiment provide important data on the evaluation of the killing potential of untried novel percussive and mechanical cervical dislocation methods on chicken cadavers. All four devices had been designed and prototyped with the aim to cause rapid loss of consciousness and brain death in order to be effective and humane. The NMCD device was shown to have the highest killing potential (100%), however, all devices achieved a killing potential of over 60%. NMCD was also shown to have the highest device success (90%), demonstrating its consistency in achieving optimal damage to the cadavers, irrespective of bird type. Device success was always lower than the killing potential for each method because it was a more specific measure. For the NMCD, MZIN and MARM the difference between the two was approximately 10%, demonstrating that these methods were not always performing optimally. For NMCD, the primary reason for this difference was the number of carotid arteries severed, as on occasion only one was severed, as well as some birds receiving a lower dislocation level than C0-C1. In the case of MZIN, the few failures in device success were due to only one region of the brain being damaged or only minor damage to all regions (e.g. internal brain cavity bleeding and bruising). Failures in device success with the MARM were primarily due to the spike not penetrating to an adequate depth to cause complete severing of the brain stem, as well as some issues with the ability to aim the device easily, and the spike not penetrating the brain stem, but instead the cerebellum. In terms of brain trauma, this could reduce the chance of neurogenic shock and elongate the time to loss of consciousness and brain death (Alexander, 1995; Dumont *et al*., 2001; Freeman and Wright, 1953; White and Krause, 1993), but it did not appear to affect the inferred kill potential (i.e. the damage would still be fatal).

The MARM and MPLI both had the lowest kill potential of 62.5%, however the MPLI had a significantly lower device success (27.5%) than its killing potential, as well as in comparison with other killing methods. The primary reasons being 55% of birds showed vertebral damage, failure of dislocation (55%) and 52.5% of birds showed trachea damage, which was representative of severe crushing injury and inference of causing death by asphyxiation, which is a serious welfare concern (Erasmus *et al.,* 2010a; Gregory and Wotton, 1990; Salim *et al.,* 2006; Sharma *et al.,* 2005).

Post-mortem measures for neck trauma methods highlighted that the MPLI was more likely (though not significant) to cause skin tears and external bleeding, which could be considered a practical issue in a commercial environment due to biosecurity, human health and safety as well as being visually un-appealing (Gerritzen and Raj, 2009; Halvorson and Hueston, 2006; Kingsten *et al*., 2005). The MPLI, which were designed to dislocate the cervical vertebrae, only caused dislocation 45% of the time and caused crushing injury to the trachea as well as to the oesophagus. The injuries sustained, as well as the pressure applied by the blades, would still be fatal, but not necessarily by causing death by cerebral ischemia, which is the desired way (Veras *et al*., 2000; Harrop *et al.,* 2001; Bader *et al.,* 2014). The primary concern with MPLI was that, despite the modifications, it was not performing in the intended way, indicating that it was not a reliable method and thus had limited humane killing potential.

Post-mortem measures demonstrated that both the MARM and MZIN always caused penetration of the skin and damage to the skull and the majority of birds bled into the external environment. There were significant differences in the areas of the brain that the two devices damaged; however, this was not an issue, as they were designed to perform differently. With the MZIN, more than 60% of all birds received damage to the main areas of brain, excluding the brain stem, demonstrating diffuse damage across the brain, which the device is designed to do in order to cause concussion and brain death (Alexander, 1995; Finnie *et al.,* 2000; Oppenheimer, 1968). The MZIN showed higher killing potential than the unmodified Rabbit Zinger™, which had previously been reported to have a kill success rate of 50% in poultry (DEFRA, 2014). The MARM caused focalised damage to the brain stem and cerebellum, highlighting that the modifications to the MARM had adequately adapted its design to more adequately fit poultry. Damage to the brain stem theoretically would result in fatal functional impairment (e.g. puntilla) (HSA, 2004; Limon *et al.,* 2009; Limon *et al.,* 2010; Morzel *et al*., 2002; Widjicks, 1995). The un-modified Armadillo® was tested previously (DEFRA, 2014), which reported it to have a low kill success of 46%, therefore the higher kill potential could be attributed to the modifications or that the killing potential was tested on cadavers, which are easier to handle, improving application of the method. The increase in success in the MZIN could be attributed to the same reasons.

Other bird factors were shown to impact some post-mortem measures (e.g. dislocation level, vertebral damage), kill potential and device success, demonstrating inconsistency dependent on the target species, although the impact was more associated with cervical dislocation methods than the head trauma methods. Bird age affected both killing potential and device success, in both cases revealing that it was easier to cause physiological trauma to younger birds and therefore easier to achieve the optimal level to achieve a reliable kill. Young birds are less physiologically mature, and therefore bones and cartilage are less calcified and re-enforced, as well as connective tissue being less fibrous, making dislocation and damage to the skull easier to achieve (Comi *et al*., 2009; Sharma *et al.,* 2005). However, in terms of neck muscle and arterial tissue, aging can have a detrimental effect, with reduced elasticity in arterial walls and skeletal muscle, reducing stretching potential, therefore carotid arteries and neck muscle are more likely to tear when under strain (Benetos *et al.,* 1993; Nair, 2005). However this needs to be considered in context of the size of the birds; smaller birds have less stretch potential than larger birds, therefore despite the increased elasticity, the magnitude of the stretch required to dislocate and tear should counteract this effect. In general, broilers and younger birds were easier to cervically dislocate, although they were confounded, as by definition broilers at both ages tested were young immature birds. The result was also supported by the diameter of the neck also affecting dislocation potential, with smaller necks (younger birds) being easier to dislocate than larger necks (older birds). When considering vertebral damage, layers were more likely to receive damage, but again bird type was confounded with age, with laying hens being much older than any other bird group. The increased likelihood of vertebral damage could be attributed to the brittle bones of the laying hens (Whitehead and Fleming, 2000). All other external factors had no impact on the post-mortem measures associated with brain trauma methods, indicating that these methods are less susceptible to inconsistency as a result of various types, size and age of birds. However, this has to be taken within the context that both of the brain trauma methods: MZIN and MARM had killing potentials of 84.2% and 62.5% respectively, both which suggest some issue with reliability.

This study was a general assessment of prototyped novel and modified devices for killing poultry on-farm, to ascertain if they showed killing potential. Three of the mechanical methods: NMCD, MARM and MZIN demonstrated killing potential, as well as consistency in physiological effects, with device success rates of over 50%, which also demonstrated that more than half the time the devices performed optimally. It was noted that in future studies more detailed assessment of post-mortem evaluations would be desirable, for example, damage location to the skull and size of dislocation (i.e. measurement of gap between two dislocated vertebrae), in order to establish in greater detail the effects on the birds' anatomy and therefore more accurately infer the effect this may have on time to unconsciousness and brain death in live birds. The MPLI did not show consistency, and had a much lower device success of 27.5%, despite matching killing potential with the MARM. The abundant evidence of crushing injury in >50% of birds, was also a major concern, especially as the new European legislation on the Protection of Animals at the Time of Killing bans by their omission, the use of any method which demonstrates death by crushing to the neck (European Council, 2009). As a result the MPLI were not recommended for a humane on-farm killing device for chickens. The remaining three devices (NMCD, MZIN, MPLI) were recommended for further assessment of performance in live birds in order to establish their suitability for a new humane method for despatching poultry on-farm.

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Table 1: Accommodation and bird details for each bird type and age group.

Bird group	N	Mean bird age at killing (days)	Mean bird weight at killing (kg)	Housed stocking density (kg/m^2)
Layer pullets	40	73.5 ± 0.2	0.8 ± 0.1	2.3
Layer hens	40	487.9 ± 0.9	1.8 ± 0.1	4.8
Broiler chicks	40	22.4 ± 0.1	0.7 ± 0.2	1.9
Broiler (slaughter age)	40	37.1 ± 0.6	1.9 ± 0.7	5.1

Table 2: Defined device success parameters for each killing device.

Device	Device success criteria
MARM	• Spike penetrates through foramen magnum of the skull • Severing of brain stem
MZIN	• Skull is penetrated and damaged • Severe damage to a minimum of one area of the brain
MPLI	• Complete cervical dislocation at C0-C1 • Severing of the top of the spinal cord (i.e. brain stem) • Severing of both carotid arteries • No breakage to the skin • No crushing injury to the trachea or oesophagus
NMCD	• Complete cervical dislocation at C0-C1 • Severing of the top of the spinal cord (i.e. brain stem) • Severing of both carotid arteries • No breakage to the skin

Table 3: Percentage of birds killed successfully for which the relevant head trauma post mortem factor was present, according to killing method. Significant P values are underlined.

	Percentage of birds			
Post mortem measure	**MZIN**	**MARM**	***F statistic***	***P value***
Skin broken	100.0	100.0	0.03	0.993
External bleeding	96.7	88.0	1.44	0.264
Subcutaneous hematoma	100.0	92.0	1.44	0.234
Skull damage	100.0	100.0	0.06	0.982
Left forebrain damage	62.5	0.0	5.81	0.029
Right forebrain damage	65.6	0.0	4.70	0.994
Cerebellum damage	65.6	64.0	0.00	0.998
Midbrain damage	84.4	0.0	5.80	0.013
Brain stem damage	31.3	92.0	5.10	0.034

Table 4: Percentage of birds killed successfully for which the relevant neck trauma post mortem factor was present, according to killing method. Significant P values are underlined.

Post mortem measure	**Percentage of birds**		***F statistic***	***P value***
	NMCD	**MPLI**		
Skin broken	7.5	20.0	0.32	0.570
External bleeding	2.5	7.5	0.06	0.805
Subcutaneous hematoma	100.0	72.5	0.00	0.994
Cervical dislocation	100.0	45.0	11.86	<0.001
Vertebral damage	5.0	55.0	3.26	0.071
≥1 carotid artery severed	95.0	15.0	6.34	0.012
Trachea damage	0.0	52.5	3.41	0.059
Oesophagus damage	0.0	12.5	0.13	0.870
Spinal cord severed	100.0	67.5	0.00	0.998

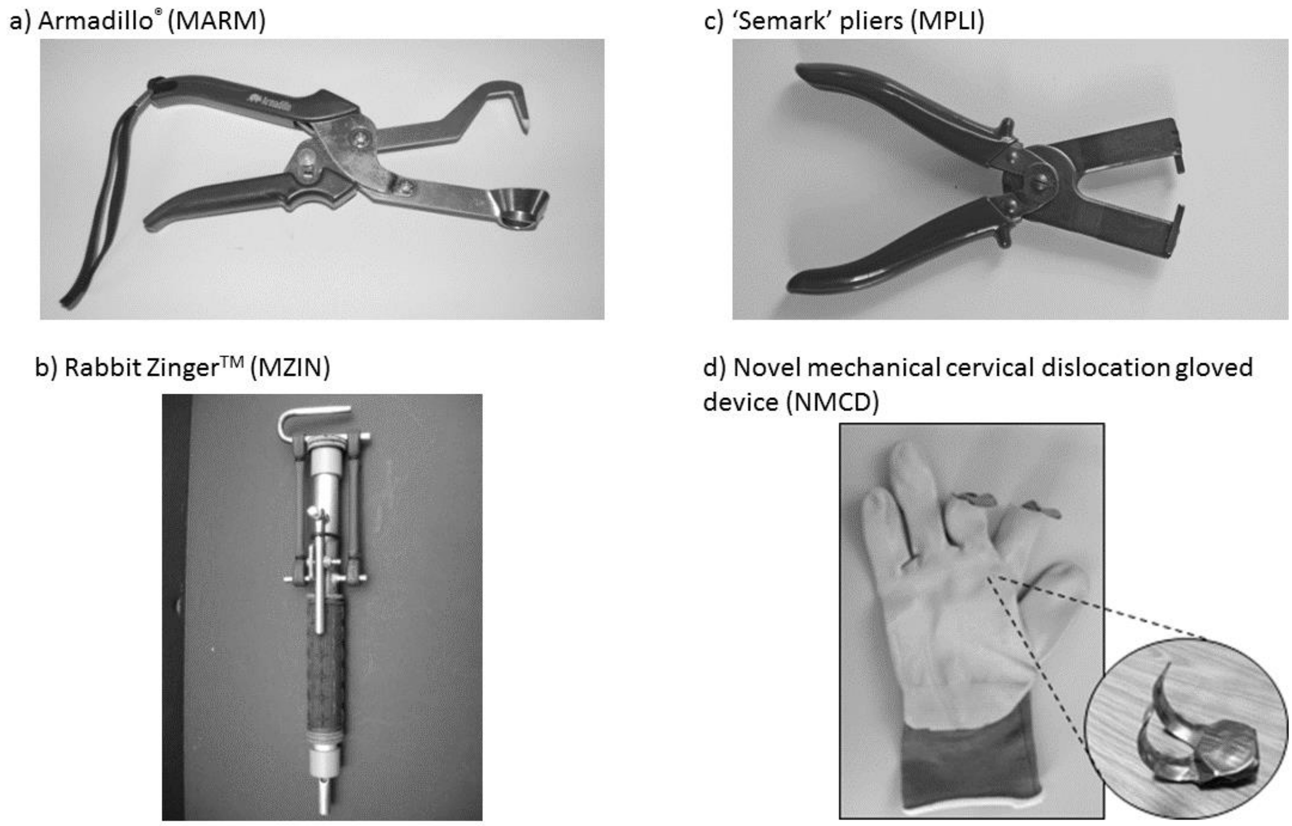

Figure 1: Photographs of devices: a) Armadillo®, b) Rabbit Zinger™, c) 'Semark' pliers, and d) the Novel mechanical cervical dislocation gloved device.

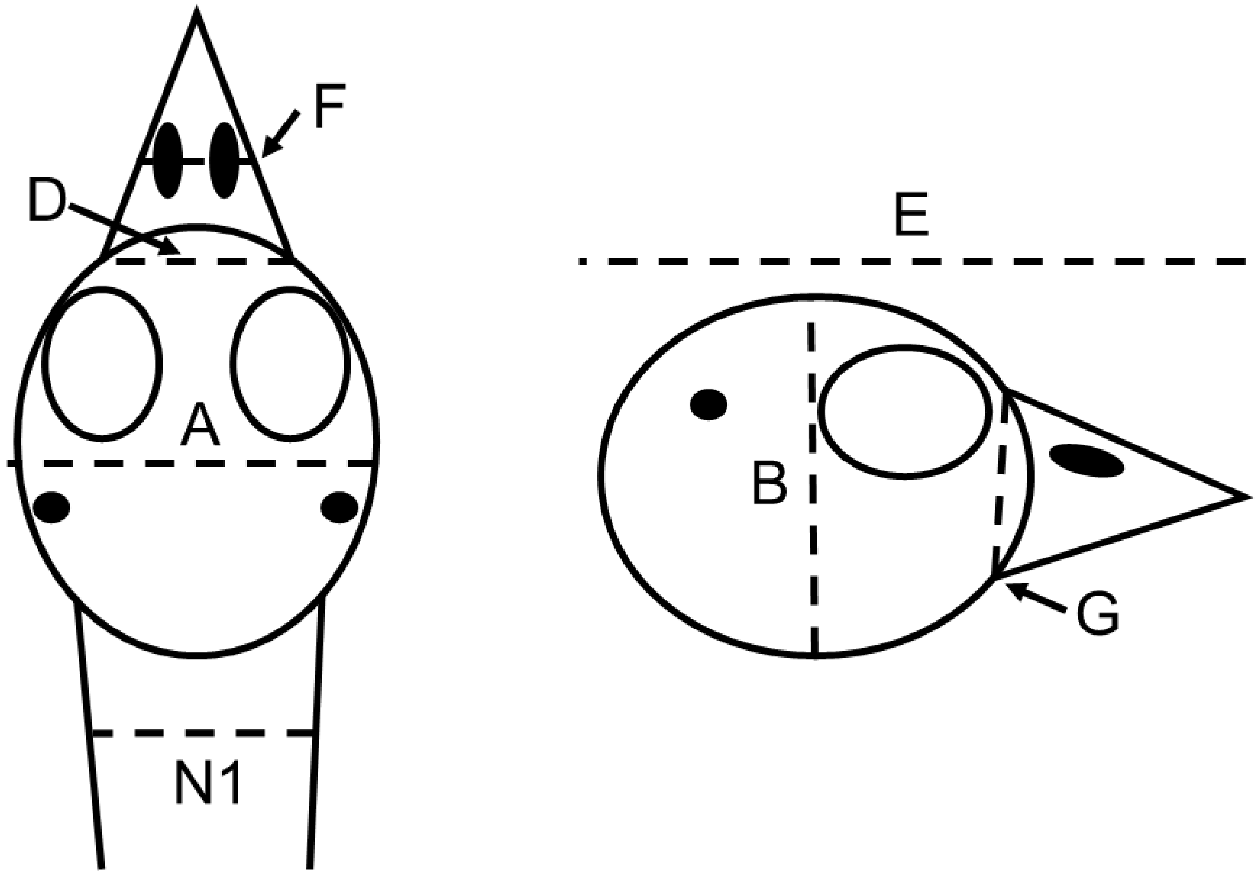

Figure 2: Schematic showing measures taken from live birds: A = width of head; B = lower jaw to top of skull; D = width of base of beak; E = base of skull to front of beak; F = width of beak at central nostril level; G = depth of beak; and N1 = width of neck.

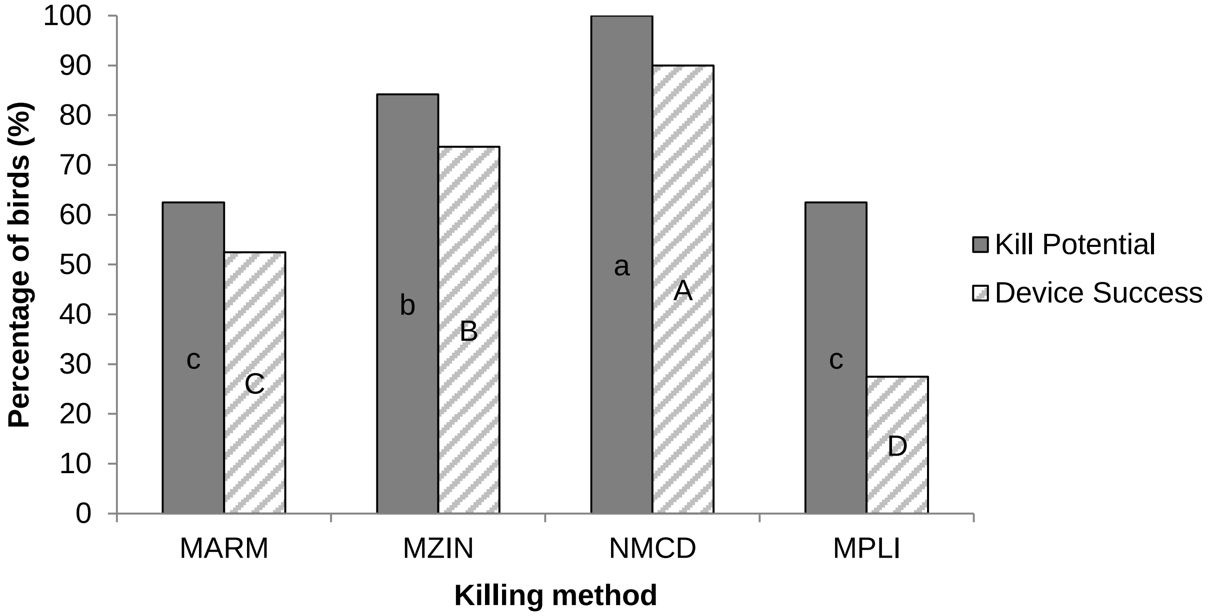

Figure 3: Summary of kill potential and device success rates (%) across the four killing devices. No common superscript indicates that there is a significant difference between the groups.

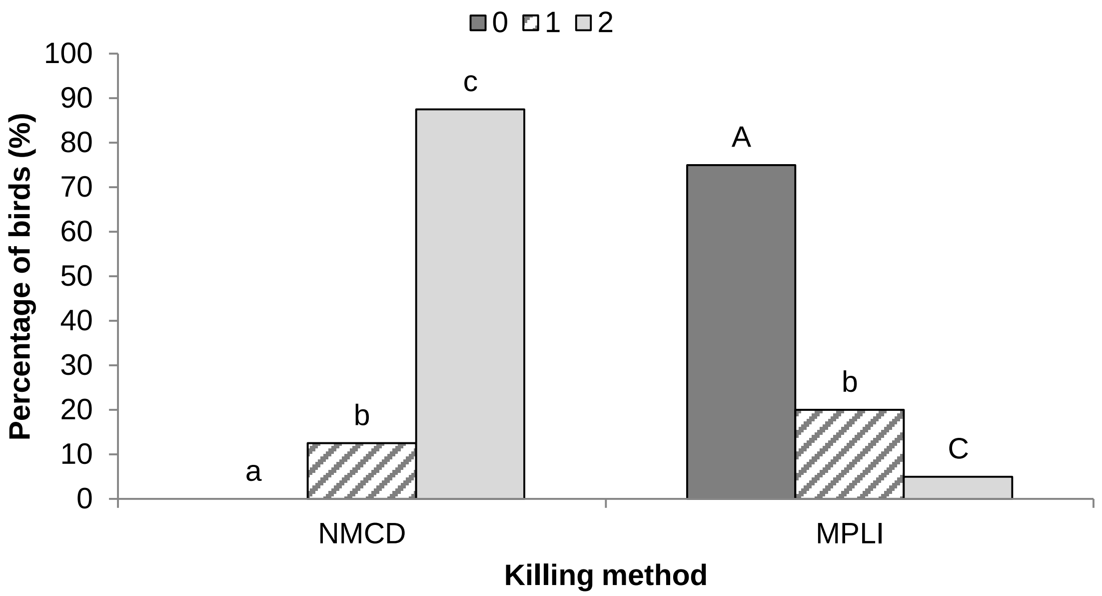

Figure 4: Percentage of birds by the number of carotid arteries severed dependent on killing method. No common superscript indicates that there is a significant difference between the groups.

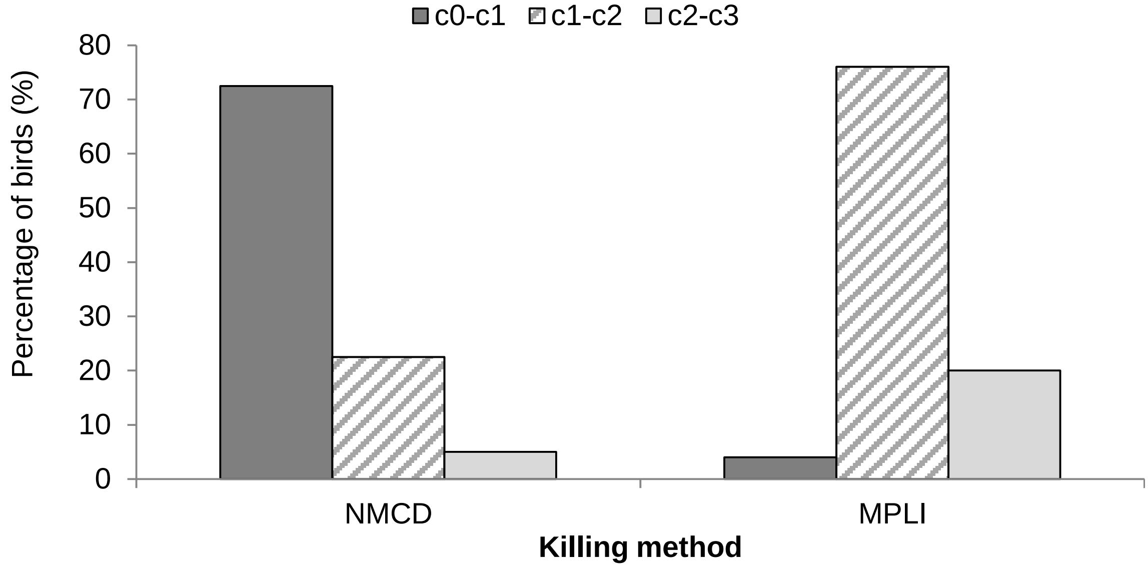

Figure 5: Distribution of birds by the various dislocation levels dependent on killing method.