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Published in:
British Poultry Science

DOI:
[10.1080/00071668.2017.1280724](https://doi.org/10.1080/00071668.2017.1280724)

First published: 15/03/2017

Document Version
Peer reviewed version

[Link to publication](#)

Citation for published version (APA):

Martin, JE., McKeegan, DEF., Sparrey, J., & Sandilands, V. (2017). Evaluation of the potential killing performance of novel percussive and cervical dislocation tools in chicken cadavers. *British Poultry Science*, 58(3), 216 - 223. Advance online publication. <https://doi.org/10.1080/00071668.2017.1280724>

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

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

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36

37 **Abstract**

- 38 1. Four mechanical poultry killing devices; modified Armadillo[®] (MARM), modified
39 Rabbit Zinger[™] (MZIN), modified pliers (MPLI) and a novel mechanical cervical
40 dislocation gloved device (NMCD), were assessed for their killing potential in cadaver
41 chickens (four bird type and age combinations: layer/adult, layer/pullet,
42 broiler/slaughter-age, broiler/chick).
- 43 2. A 4x4x4 factorial design (batch x device x bird type + age) was employed. Ten birds
44 per bird type (+ age) were tested with each of the four mechanical devices (N = 160
45 birds). All birds were examined post-mortem in order to establish the anatomical
46 damage sustained to the bird by the device.
- 47 3. Three of the mechanical methods: NMCD, MARM and MZIN demonstrated killing
48 potential, as well as consistency in physiological effects, with device success rates of
49 over 50%, indicating that more than half the time the devices performed optimally.
50 NMCD had the highest kill potential, with 100% of birds sustaining the required
51 physiological trauma to have caused rapid death.
- 52 4. The MPLI did not show consistency, and only performed optimally for 27.5% of birds,
53 despite matching killing potential with the MARM. Severe crushing injury was seen in
54 >50% of MPLI birds, suggesting birds would die of asphyxia rather than cerebral
55 ischemia, a major welfare concern. As a result the MPLI are not recommended as a
56 humane on-farm killing device for chickens.
- 57 5. The results of this experiment provide important data on the evaluation of the killing
58 potential of untried novel percussive and mechanical cervical dislocation methods on
59 chicken cadavers.

60

61

62 **Keywords**

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

64

65 **Introduction**

66 Worldwide, an estimated 9.1 billion birds may need to be killed on farm each year (DEFRA
67 2015) and the method in which these birds are killed is crucial to poultry welfare on a large
68 scale. Poultry may need to be killed on-farm for multiple reasons (e.g. injury, sickness and
69 for stock management). Emergency killing on a large scale is often controlled by whole-
70 house or containerised gas methods (e.g. Lambooij *et al.*, 1999; Gerritzen *et al.*, 2004;
71 Gerritzen *et al.*, 2009; McKeegan *et al.*, 2011). For individual birds on-farm, there are two
72 main methods for killing poultry: (i) cervical dislocation, which is designed to cause death by
73 cerebral ischaemia and extensive damage to the spinal cord and brainstem (Ommaya &
74 Gennarelli 1974; Gregory & Wotton 1990; Erasmus *et al.*, 2010a,b; Bader *et al.*, 2014; Martin
75 *et al.*, 2016); and (ii) percussive devices designed to cause extensive brain damage,
76 resulting in brain death (Gregory & Wotton, 1990; HSA, 2004; Mason *et al.*, 2009; Erasmus
77 *et al.*, 2010a,b; Sparrey *et al.*, 2014; Cors *et al.*, 2015).

78

79 Cervical dislocation has been shown to be one of the most prevalent methods for killing
80 individual birds and is used in commercial and non-commercial contexts, as it is perceived to
81 be humane by users, easy to learn and perform, and does not require equipment (Mason *et*
82 *al.*, 2009; Sparrey *et al.*, 2014; Martin, 2015; Martin *et al.*, 2016). Both manual and
83 mechanical cervical dislocation killing methods are designed to separate the skull from the
84 vertebral column of the bird (C0–C1 vertebral dislocation), resulting in severing of the spinal
85 cord and/or brainstem and the main blood vessels supplying the brain (Gregory & Wotton,
86 1990; Parent *et al.*, 1992; Veras *et al.*, 2000; Cartner *et al.*, 2007; Mason *et al.*, 2009). It has
87 been suggested that optimal application also produces a concussive effect on the bird due to
88 trauma inflicted on the brainstem through the action of stretching and twisting (Harrop *et al.*,
89 2001; Shi & Pryor, 2002; Pryor & Shi, 2006; Shi & Whitebone, 2006; Cartner *et al.*, 2007;
90 Erasmus *et al.*, 2010a). However, both methods of cervical dislocation have been the subject
91 of welfare concern, as research in the last 40 years has questioned their humaneness and
92 consistency in poultry (Gregory & Wotton, 1986, 1990; Erasmus *et al.*, 2010a), as well as

93 other species (Tidswell *et al.*, 1987; Cartner *et al.*, 2007). Some studies have indicated that
94 animals, including poultry, may be conscious for a significant period post-application of
95 cervical dislocation methods (Gregory & Wotton, 1990; Erasmus *et al.*, 2010a; Carbone *et*
96 *al.*, 2012) and it has been noted that there is high variability in its application by different
97 relevant groups (e.g. poultry stock-workers, veterinarians, trained slaughtermen) (Mason *et*
98 *al.*, 2009; Sparrey *et al.*, 2014). As of January 2013 the use of manual cervical dislocation
99 (MCD) as a killing method for poultry on-farm has been heavily restricted through the new
100 EU legislation, Regulation (EC) no. 1099/2009 On the Protection of Animals at the Time of
101 Killing (European Commission, 2009), following reported welfare concerns. FAWC (2009)
102 recommended research to explore current and novel methods for killing poultry in small
103 numbers. Several mechanical devices have been developed recently (e.g. CASH Poultry
104 Killer, Turkey Euthanasia Device) (Erasmus *et al.*, 2010a; Erasmus *et al.*, 2010b; HSA,
105 2004; Raj and O'Callaghan, 2001), however, none have been enthusiastically adopted
106 across the commercial industry or by small poultry keepers.

107

108 Previous research has shown that post-mortem analysis is effective in inferring killing
109 potential and time to loss of consciousness and has been used across several species in
110 determining success rates of slaughter and on-farm killing method in livestock species (e.g.
111 Anil *et al.*, 2002; Grandin, 2010; Morzel *et al.*, 2002; Bader *et al.*, 2014). For example the
112 successful application of cervical dislocation methods is determined by the animal having its
113 neck dislocated and the spinal cord severed (Bader *et al.*, 2014; Carbone *et al.*, 2012;
114 Cartner *et al.*, 2007; Erasmus *et al.*, 2010a), while for concussive (head trauma) devices,
115 there must be sufficient damage (e.g. skull fractures, brain contusions, cerebral oedema,
116 hemorrhaging and *contra-coup* damage) (Finnie *et al.*, 2000; Finnie *et al.*, 2002; Gregory *et*
117 *al.*, 2007; Gregory and Shaw, 2000). Determining the success rate of a killing device is
118 essential to evaluating its overall efficacy. The designing and prototyping of novel and
119 modified devices is the first stage in tool development and a hopeful provision of a new
120 humane device to despatch poultry on-farm. This study assesses the potential kill

121 performance of four novel or modified mechanical devices on both layer and broiler
122 cadavers, through post-mortem analysis to establish whether the devices should be taken
123 forward and evaluated in live and conscious birds as potential new on-farm killing methods
124 for chickens.

125

126

127 **Methods**

128 *Subjects and husbandry*

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

134

135 The birds were housed for one week prior to the experiment in order to allow them to
136 acclimatise to the new environment. Birds were housed in separate rooms per bird type and
137 age group to provide recommended environmental controls (Aviagen, 2009; Hy-Line, 2012).
138 All birds were kept in floor pens with wood-shavings litter at significantly lower than
139 commercial stocking density and with various environmental enrichments (e.g. suspended
140 CDs, perches) (DEFRA, 2002a; DEFRA, 2002b). All pens were constructed from wooden
141 frames with wire-grid sides and roofs, allowing visual and auditory contact with other birds
142 within the same room. Broiler chicks and layer pullets were housed in group pens (L 1.5 m x
143 W 2.5 m x H 1.5 m). Broilers (slaughter-age) and layer hens were kept in pairs. Pen sizes
144 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
145 water. All birds were inspected twice daily, and the minimum and maximum temperatures
146 were recorded each morning.

147

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

151

152 *Experimental Procedure*

153 Four mechanical poultry killing devices: modified Armadillo® (MARM), modified Rabbit
154 Zinger™ (MZIN), modified pliers (MPLI) and a novel mechanical cervical dislocation gloved
155 device (NMCD) were assessed for their killing potential in cadaver birds (four bird type and
156 age combinations). All methods developed are discussed in detail in Martin, 2015 and were
157 designed to comply with the current European legislation, EC1099/2009 (European Council,
158 2009). Briefly, the Armadillo® (shown in Figure 1a) is a brain-stem penetrating device
159 designed by a veterinarian (John Dalton) to dispatch game birds in the field (Sparrey *et al.*,
160 2014; Martin, 2015). The device is a scissor-type mechanism (approximately 17 cm in
161 length), in which the bird's head is placed into the 'cup' of the lower arm (beak facing
162 downwards) and when ready to apply the operator squeezes the handles together, which
163 pushes the top arm (and the penetrating spike) downwards into the back of the bird's skull,
164 preferably through the foramen magnum therefore severing the top of the spinal cord (or
165 brain stem), and causing death by cerebral ischemia. Presently there is no published
166 scientific evidence on the efficacy of this device. Modifications (with permission of inventor)
167 consisted of replacing the lower arm of the device in order to increase the upper (U) (33 mm
168 to 37 mm) and lower (L) (19 mm to 27 mm) diameters of the openings of the metal cup
169 based on pilot work demonstrating the need for a more space to encompass chicken heads.
170 Additional insertion cups were molded from 1mm thick plastic funnels, in order to generate
171 two adjustments (G1, G2) to fit the various sizes of birds' heads, based on bird type and age
172 (G1: U=36 mm and L=23 mm (broiler, layer hen); G2: U=30 mm and L=18 mm (layer pullets,
173 broiler chicks)). The additional cups also had soft padding (Waxman 4719095N ½ inch Self
174 Stick Felt Pads, Waxman, Ohio, United States) added to their sides, which cushioned the

175 lateral sides of the bird's head (over the eyes) as well as creating an oval shape for the
176 upper opening.

177

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

194

195 Cervical dislocation pliers have been reported as popular amongst the poultry industry
196 (Sparrey *et al.*, 2014; Martin, 2015), however, research has demonstrated they do not cause
197 an immediate loss of consciousness (e.g. loss of Visual Evoked Responses (VERs) as a
198 possible indicator of loss of consciousness (Gregory and Wotton, 1990)), and in the
199 'Semark' pliers have a low success rate in fully dislocating the neck and severing the spinal
200 cord (Gregory and Wotton, 1990) and are suggested to cause crushing injury (DEFRA,
201 2014). 'Semark' pliers (also known as the 'Humane Bird Dispatcher') weigh approximately
202 200 g and have an overall length of 180 mm. When the blades of the device are fully open

203 the maximum distance between the upper and lower teeth is 36 mm. When the blades are
204 fully closed there is a slight gap between the blades (<1 mm). The pliers were modified
205 (MPLI) in an attempt to reduce crushing injury by adapting the shape and width of the blades
206 in order to create a narrower, curved concave edge rather than a straight edge (Martin,
207 2015). The edges of the blades remained blunt in order to reduce the risk of skin tearing and
208 thus blood loss during application of the method. It was hypothesised that by narrowing the
209 edge of the blade it would reduce the risk of crushing and would instead increase the
210 likelihood of dislocation, as the narrower blade would more easily slip between two cervical
211 vertebra when force was applied. The blades were widened gradually to increase the size of
212 the blade (over 3 mm) and therefore generate a dislocation (i.e. gap between the two
213 vertebra), through pushing the vertebrae apart.

214

215 The NMCD device (Figure 1d) was designed to create a mechanical method for cervical
216 dislocation of poultry which mirrored the technique of the manual method (described in
217 Martin, 2015; Martin et al., 2016). The device consisted of a thin supportive glove (SHOWA
218 370 Multipurpose Stable GloveTM, UK) designed to support the wrist and hand (and therefore
219 hypothesised to reduce strain injury in the operator) and a moveable metal insert. The metal
220 insert was made up of two metal finger supports and were designed to fit around the bird's
221 head to create a secure grip, and to move independently from side-to-side in order to allow
222 adjustment for different sizes of birds (Figure 1d). The rounded shape of the metal fingers
223 was designed to aid the twisting motion (performed during manual cervical dislocation
224 (Sparrey *et al.*, 2014; Martin *et al.*, 2016)) required to dislocate the bird's neck by enhancing
225 the 'rolling action' of the hand. The blunt edge between the two metal fingers (protruding < 1
226 mm from the fleshy area of skin between the index and middle fingers) provided a hard edge
227 to force between the back of the bird's head and the top of the neck, designed to focalise the
228 force into the desired area (i.e. a dislocation at C0–C1) when the method was applied.

229

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

237

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

244

245 After device application, the cadavers were immediately examined post-mortem in order to
246 establish as accurately as possible the anatomical damage sustained to the bird by the
247 device. Specific post-mortem measures were recorded for each killing device as their target
248 anatomical areas were different. For all killing devices binary measures were recorded for
249 skin broken, external blood loss and subcutaneous hematoma and the total number of
250 attempts were recorded (e.g. multiple pulls for NMCD or miss-fire of MZIN). For the MZIN
251 and MARM, seven specific measures were recorded: binary measures of damage to the
252 skull, specific brain regions (left forebrain, right forebrain, cerebellum, midbrain and
253 brainstem); and the presence of an internal brain cavity hematoma. For killing devices which
254 caused trauma to the neck of the bird (NMCD and MPLI), seven specific post-mortem
255 measures were assessed: four binary measures were recorded for dislocation of the neck,
256 vertebra damage (e.g. intra-vertebra dislocation/break), damage to neck muscle, crushing
257 injury to the trachea or oesophagus and whether the spinal cord was severed. The level of

258 cervical dislocation was recorded (e.g. between C0-C1, C1-C2, C2-C3, etc.), as well as a
259 measurement of the length (cm) of the gap between the dislocated cervical vertebra. The
260 number of carotid arteries severed was also recorded as zero, one or both.

261

262 *Derived kill potential and device success*

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

270

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

276

277 **Statistical Analysis**

278 All data were summarised in Microsoft Excel (2010) spread sheets and analysed using
279 Genstat (14th Edition). Statistical significance was based on F statistics and $P < 0.05$
280 significance level. Summary graphs and statistics were produced at bird and treatment level.
281 Generalised Linear Mixed Models (GLMM) (binomial distribution) were used to compare
282 performance across the four killing devices in terms of kill potential and device success,
283 while incorporating bird type, age, and block as fixed effects and bird weight head
284 measurements as co-variates. Batch was included as a random effect. Detailed comparisons
285 of device performance were achieved by sub setting the data twice: initially to remove

286 unsuccessfully “killed” birds (i.e. kill potential “no”) in order to prevent data skewing; and then
287 into two groups dependent on trauma area: 1) neck trauma (NMCD and MPLI); and (2) head
288 trauma (MZIN and MARM), in order to allow logical comparison between killing treatments
289 which damaged the neck or the head. Statistical comparisons on anatomical measures were
290 conducted via GLMMs (Poisson distribution and binomial distribution) or Linear Mixed
291 Models (LLM) (normal distribution) dependent on the data distributions for each variable.
292 Data transformations were attempted when necessary via Logarithm function. All models
293 included batch number as random effects. All fixed effects were treated as factors and
294 classed as categorical classifications and all interactions between factors were included in
295 maximal models.

296

297 **Results**

298 A total of 36 birds were not successfully “killed” on the first attempt (NMCD = 0/40 birds;
299 MPLI = 15/40 birds; MARM = 15/40 birds; and MZIN = 6/40 birds). Device had an effect on
300 kill potential ($F_{(3,144)}=2.88$, $P=0.038$), with NMCD having the highest kill potential, with 100%
301 of birds sustaining the required physiological trauma to have caused death (Figure 3). The
302 MARM and MPLI had the lowest kill potential, with both achieving 62.5%. Bird age was the
303 only other factor to affect kill potential ($F_{(1,144)}=5.15$, $P=0.025$), with younger birds being more
304 likely to sustain the required physiological trauma to have resulted in death (mean = $0.87 \pm$
305 0.04), compared to older birds (mean = 0.68 ± 0.05). All other factors (e.g. bird weight, type)
306 and their interactions had no effect on kill potential.

307

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

314

315 *Percussive methods*

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

326

327 *Cervical dislocation methods*

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

338

339 Whether or not cervical dislocation (no = 0; yes = 1) occurred was significantly affected by
340 bird type ($F_{1,74}=5.98$, $P=0.014$) and bird age ($F_{1,74}=6.39$, $P=0.011$), with dislocations more
341 likely to occur in broilers (mean = 0.95 ± 0.05) rather than layers (mean = 0.55 ± 0.11), and

342 younger birds (mean = 0.90 ± 0.07) compared to older birds (mean = 0.60 ± 0.11). The
343 diameter of the birds' necks (N1) ($F_{1,74}=4.00$, $P=0.050$) was also shown to have an effect
344 with unsuccessful dislocations associated with larger neck diameters (17.1 ± 1.09 mm)
345 compared to successful dislocations (14.9 ± 0.51 mm). Bird type had an effect on the
346 likelihood of vertebral damage (no = 0; yes = 1), with layers (mean = 0.75 ± 0.10) more likely
347 to sustain damage than broilers (mean = 0.35 ± 0.11). No other factors or interactions, apart
348 from killing method (reported above) had an effect on vertebral damage.

349

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

356

357 **Discussion**

358 The results of this experiment provide important data on the evaluation of the killing potential
359 of untried novel percussive and mechanical cervical dislocation methods on chicken
360 cadavers. All four devices had been designed and prototyped with the aim to cause rapid
361 loss of consciousness and brain death in order to be effective and humane. The NMCD
362 device was shown to have the highest killing potential (100%), however, all devices achieved
363 a killing potential of over 60%. NMCD was also shown to have the highest device success
364 (90%), demonstrating its consistency in achieving optimal damage to the cadavers,
365 irrespective of bird type. Device success was always lower than the killing potential for each
366 method because it was a more specific measure. For the NMCD, MZIN and MARM the
367 difference between the two was approximately 10%, demonstrating that these methods were
368 not always performing optimally. For NMCD, the primary reason for this difference was the
369 number of carotid arteries severed, as on occasion only one was severed, as well as some

370 birds receiving a lower dislocation level than C0-C1. In the case of MZIN, the few failures in
371 device success were due to only one region of the brain being damaged or only minor
372 damage to all regions (e.g. internal brain cavity bleeding and bruising). Failures in device
373 success with the MARM were primarily due to the spike not penetrating to an adequate
374 depth to cause complete severing of the brain stem, as well as some issues with the ability
375 to aim the device easily, and the spike not penetrating the brain stem, but instead the
376 cerebellum. In terms of brain trauma, this could reduce the chance of neurogenic shock and
377 elongate the time to loss of consciousness and brain death (Alexander, 1995; Dumont *et al.*,
378 2001; Freeman and Wright, 1953; White and Krause, 1993), but it did not appear to affect
379 the inferred kill potential (i.e. the damage would still be fatal).

380

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

388

389 Post-mortem measures for neck trauma methods highlighted that the MPLI was more likely
390 (though not significant) to cause skin tears and external bleeding, which could be considered
391 a practical issue in a commercial environment due to biosecurity, human health and safety
392 as well as being visually un-appealing (Gerritzen and Raj, 2009; Halvorson and Hueston,
393 2006; Kingsten *et al.*, 2005). The MPLI, which were designed to dislocate the cervical
394 vertebrae, only caused dislocation 45% of the time and caused crushing injury to the trachea
395 as well as to the oesophagus. The injuries sustained, as well as the pressure applied by the
396 blades, would still be fatal, but not necessarily by causing death by cerebral ischemia, which
397 is the desired way (Veras *et al.*, 2000; Harrop *et al.*, 2001; Bader *et al.*, 2014). The primary

398 concern with MPLI was that, despite the modifications, it was not performing in the intended
399 way, indicating that it was not a reliable method and thus had limited humane killing
400 potential.

401

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

420

421 Other bird factors were shown to impact some post-mortem measures (e.g. dislocation level,
422 vertebral damage), kill potential and device success, demonstrating inconsistency
423 dependent on the target species, although the impact was more associated with cervical
424 dislocation methods than the head trauma methods. Bird age affected both killing potential
425 and device success, in both cases revealing that it was easier to cause physiological trauma

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

449

450 This study was a general assessment of prototyped novel and modified devices for killing
451 poultry on-farm, to ascertain if they showed killing potential. Three of the mechanical
452 methods: NMCD, MARM and MZIN demonstrated killing potential, as well as consistency in
453 physiological effects, with device success rates of over 50%, which also demonstrated that

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

468

469 **Acknowledgements**

470 This research was supported and funded by the Humane Slaughter Association (HSA), UK.

471

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625

626 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/m²)
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

627

628

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

Device	Device success criteria
MARM	<ul style="list-style-type: none"> • Spike penetrates through foramen magnum of the skull • Severing of brain stem
MZIN	<ul style="list-style-type: none"> • Skull is penetrated and damaged • Severe damage to a minimum of one area of the brain
MPLI	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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

630

631

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

Post mortem measure	Percentage of birds		<i>F</i> statistic	<i>P</i> value
	MZIN	MARM		
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	<u>0.029</u>
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	<u>0.013</u>
Brain stem damage	31.3	92.0	5.10	<u>0.034</u>

634

635

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

Post mortem measure	Percentage of birds		<i>F statistic</i>	<i>P value</i>
	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	<u>≤0.001</u>
Vertebral damage	5.0	55.0	3.26	0.071
≥1 carotid artery severed	95.0	15.0	6.34	<u>0.012</u>
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

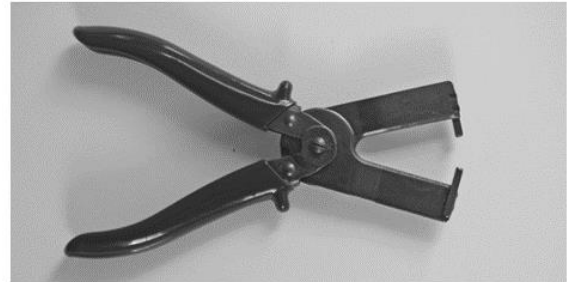
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639

a) Armadillo® (MARM)



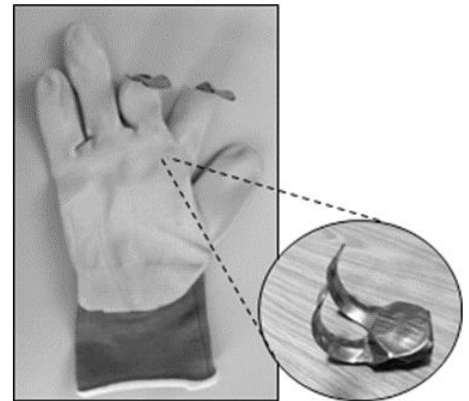
c) 'Semark' pliers (MPLI)



b) Rabbit Zinger™ (MZIN)



d) Novel mechanical cervical dislocation gloved device (NMCD)

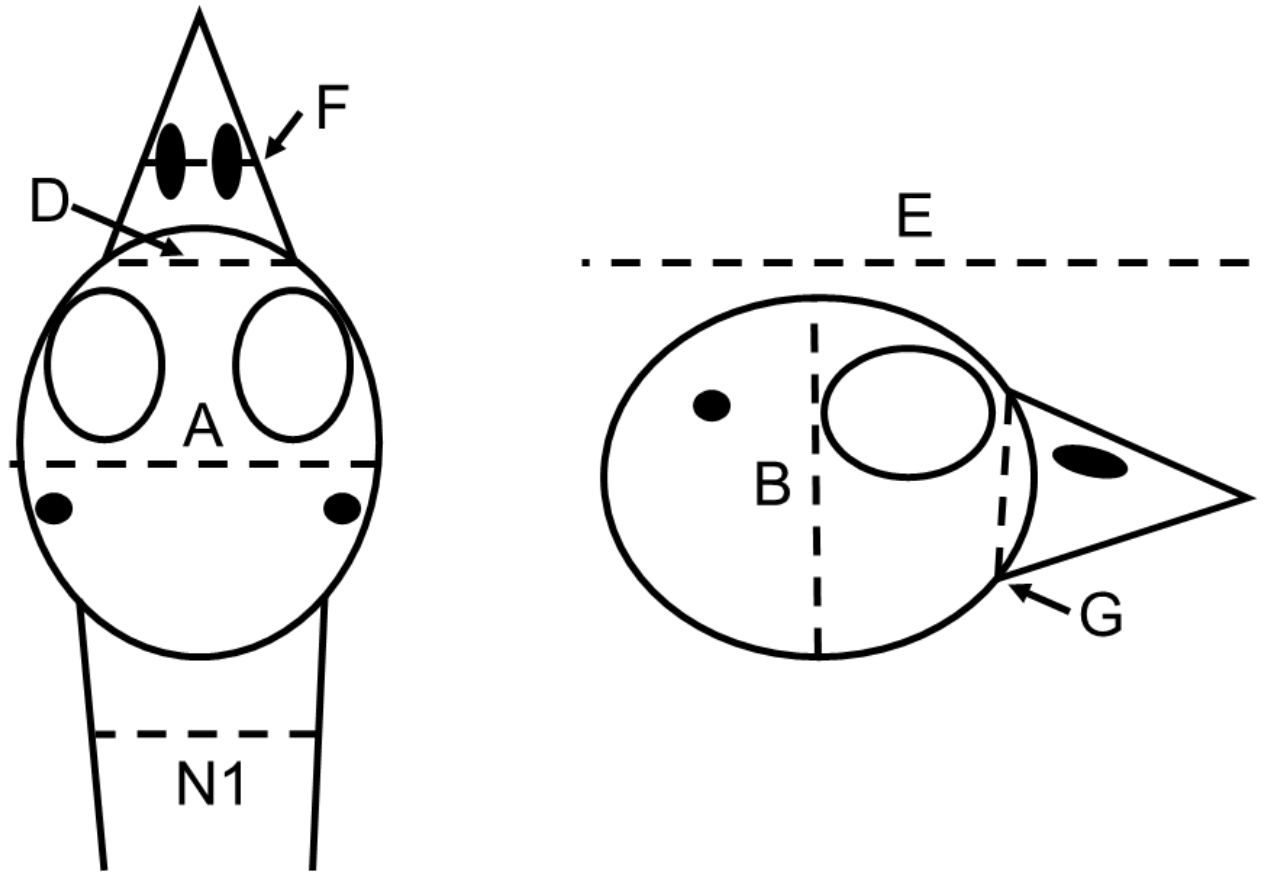


640

641 Figure 1: Photographs of devices: a) Armadillo®, b) Rabbit Zinger™, c) 'Semark' pliers, and

642 d) the Novel mechanical cervical dislocation gloved device.

643



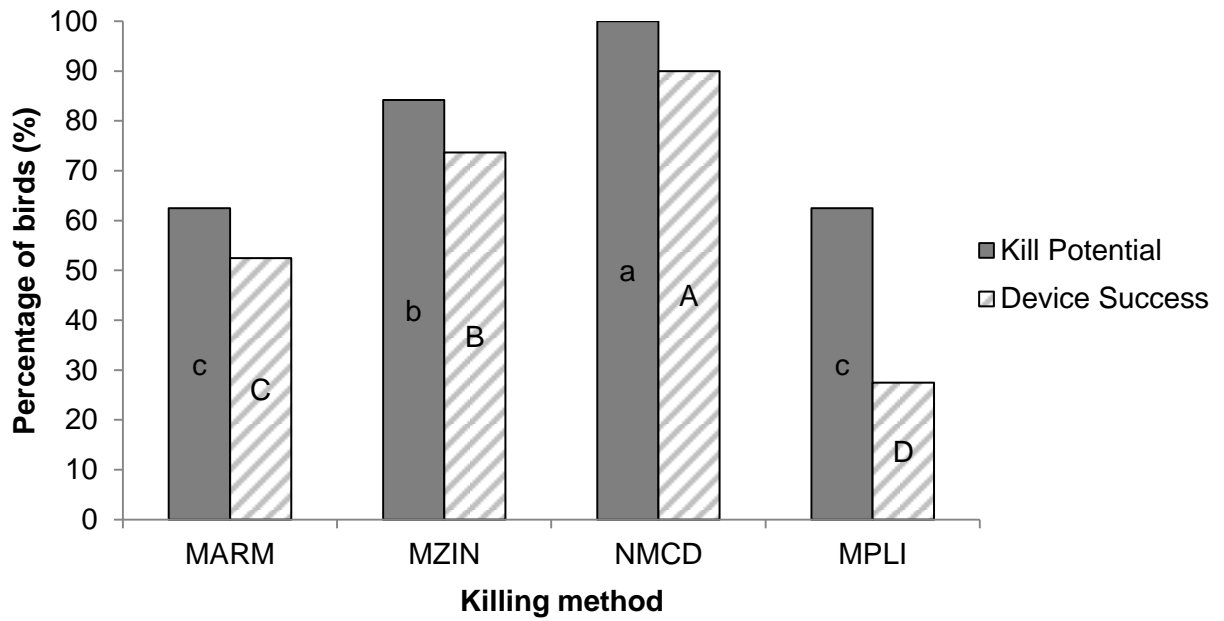
644

645 Figure 2: Schematic showing measures taken from live birds: A = width of head; B = lower

646 jaw to top of skull; D = width of base of beak; E = base of skull to front of beak; F = width of

647 beak at central nostril level; G = depth of beak; and N1 = width of neck.

648

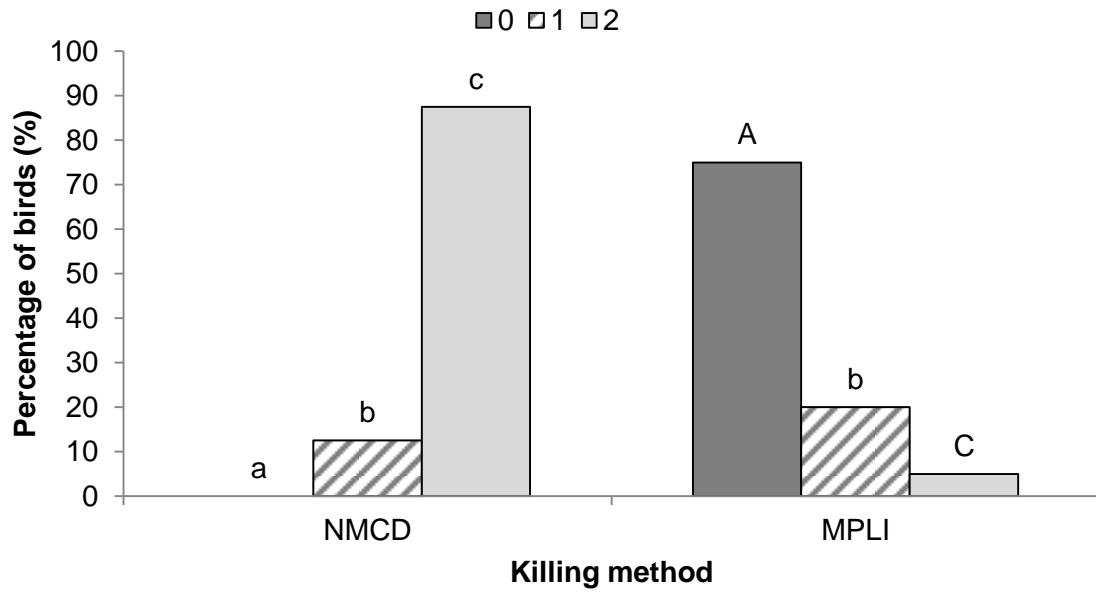


649

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

653

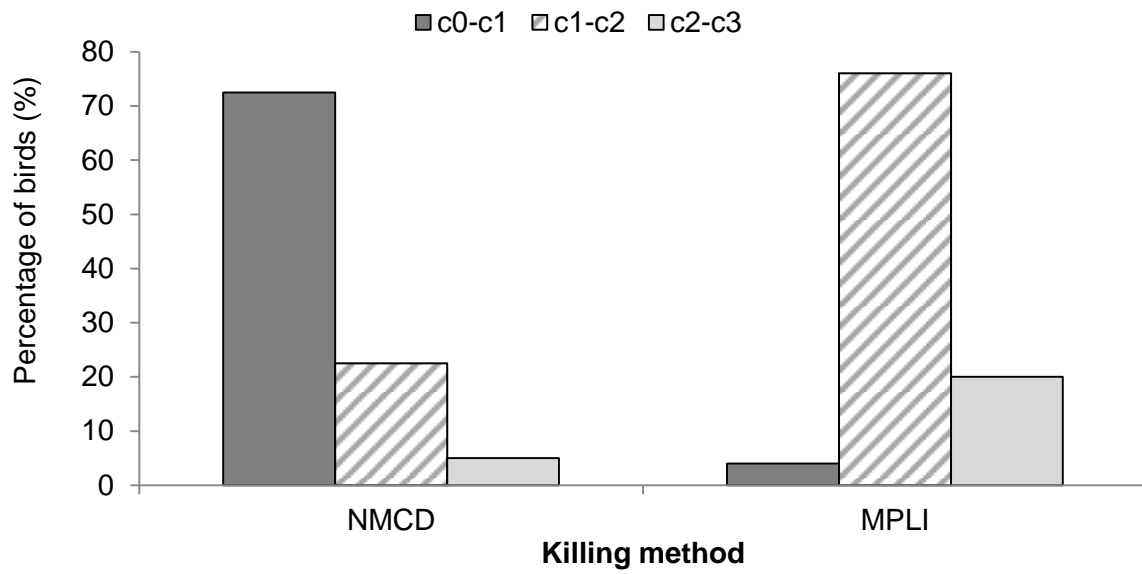
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655

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

659



660

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