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Broiler carcass quality using head-only electrical stunning in a waterbath.

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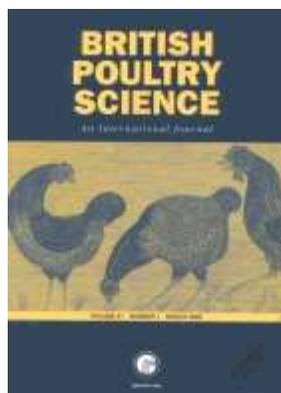
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Broiler carcass quality using head-only electrical stunning in a waterbath.

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3 **1 Broiler carcass quality using head-only electrical stunning in a waterbath.**
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3
4 22 **Abstract** 1. The objective of the experiment was to assess the carcass quality of broilers
5
6 23 when they were stunned by immersing their heads in a waterbath with an electric current
7
8 24 flowing from one side to the other, while a second current passed through the body to the
9
10 25 waterbath to prevent involuntary wing flapping.
11
12 26 2. The prevalence of wing, shoulder and breast fillet haemorrhages and broken bones in the
13
14 27 pectoral region was not greater than that resulting from the normal stunning practice in the
15
16 28 plant (63 mA, 610 Hz pDC).
17
18 29 3. The results imply that carcass damage using this technique will be significantly lower than
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20 30 that which will result from the application higher stunning currents required by the new EU
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22 31 poultry slaughter regulations.
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34 INTRODUCTION

35 Eight hundred and thirty million broilers are slaughtered each year in the UK, about three
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37 36 quarters of which are killed on a shackle line using electrical waterbath stunning (Anon
38
39 37 2007). In traditional waterbath stunning an electric current passes from the waterbath,
40
41 38 through the head, body and legs of the bird, and into the shackle. When suitable electrical
42
43 39 parameters are used, this electric current stuns the bird and immobilises the body. However
44
45 40 the current also causes broken bones and haemorrhagic damage to a proportion of the
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47 41 carcasses. Since 60% of broilers are sold deboned, this carcass damage is clearly visible to
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49 42 the purchaser and reduces the value of the meat.
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44 The prevalence of carcass damage can be reduced by decreasing the stunning current or
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46 45 increasing its frequency (Veerkamp and de Vries 1983; Gregory and Wilkins 1989; Gregory
et al 1995). However these changes also decrease the reliability with which the birds are

1
2
3 47 stunned (Raj *et al.* 2006a,b). Selection of the parameters of the stunning current therefore
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5 48 requires that the welfare needs of the broilers are balanced against the commercial needs of
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7
8 49 the processing plant. Not surprisingly, the relative emphasis given to these aspects is
9
10 50 differently by different sections of society.
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15 52 Research by Raj *et al.* (2004, 2006a, 2006b) indicates that the electric stunning parameters
16
17 53 currently used in the industry (typically 600 Hz Pulsed DC current at 80mA rms per bird) do
18
19
20 54 not necessarily result in immediate unconsciousness for all birds. New EC regulations on the
21
22 55 protection of animals at the time of killing (EC, 2009) will, from 2013, require the use of
23
24 56 minimum stunning currents of 100 mA for frequencies up to 200 Hz, of 150 mA for
25
26 57 frequencies of 200-400 Hz and of 200 mA for frequencies of 400-1500 Hz. Barker (2006)
27
28 58 indicated that these changes are expected to result in significant increases in carcass damage
29
30 59 resulting in a cost to the UK industry over £18m and require an additional 30 million birds to
31
32 60 provide sufficient undamaged fillets.
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36 61
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39 62 There are indications that head-only electrical stunning results in low levels of carcass
40
41 63 damage (Kranen, 1996) however, the difficulty of accurately and rapidly applying the
42
43 64 electrodes to the birds' heads means that it is currently not suitable for use in high throughput
44
45 65 commercial plants.
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51 67 Recently, a new concept in head-only stunning was investigated by Lines *et al.* (2011). This
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53 68 method does not require electrodes to be applied directly to the bird's head but rather requires
54
55 69 them to be dipped into a waterbath which has an electric current flowing across it from one
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57 70 side of the waterbath to the other. This is fundamentally different from the conventional
58
59 71 waterbath where the stunning current runs from the waterbath through the bird's body to the
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1
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3 72 shackles. Since the bird's head does not need to be located and electrodes applied directly,
4
5 73 the approach may be suitable for high-speed application in commercial poultry processing
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8 74 plants. In the investigation, electrical stunning parameters which resulted in immediate and
9
10 75 prolonged insensibility were identified and a means to prevent the violent involuntary wing
11
12 76 flapping which is normally associated with head-only stunning was demonstrated. The
13
14 77 practical significance of this development, however, depends on the effect this approach has
15
16 78 on carcass quality.
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21
22 80 In this paper we report the results of trials designed to examine the carcass damage in birds
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24 81 slaughtered using the head-only waterbath stunning technique. The results are compared
25
26 82 against control birds which were killed using a normal waterbath stunning system in a
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28 83 commercial processing plant. By comparing these results against the work of Barker (2006),
29
30 84 we make assess the carcass quality obtained by waterbath head-only stunning, those currently
31
32 85 achieved in a commercial poultry processing plants, and those which would be obtained using
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34 86 the stunning currents recommended by Raj (2006a,b). The latter are similar to those which
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36 87 will be mandatory in the EU from 2013 (EC 2009).
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42 43 89 **MATERIALS AND METHODS**

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48 91 Broiler carcass damage measurements were made in two separate but similar studies which
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50 92 took place on separate days during the same week in the same commercial poultry processing
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52 93 plant.
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3 95 The trials were carried out as a University of Bristol investigation following the approval of the
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5 96 local ethics committee. The stunning methodology that was used had previously been developed and
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7 97 tested under Home Office licence.
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12 99 ***Study 1***

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15 100 This trial was carried out at a large commercial poultry slaughter plant almost completely
16
17 101 dedicated to slaughtering broiler chickens. Over a period of approximately 5 hours from
18
19 102 08.00, 300 male broilers of 47 days of age and of average live weight 3.49 kg were
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21 103 individually removed from the shackle line post hang-on but before the stun bath. They were
22
23 104 transferred to a single shackle suspended on a rope and, when settled, their heads were
24
25 105 lowered smoothly into the experimental head-only waterbath stunner. Each bird was
26
27 106 subjected to an electrical stun and then immediately transferred to a second shackle on an
28
29 107 adjacent fixed frame where an experienced slaughterman employed at the poultry plant cut its
30
31 108 neck manually, with the aim of severing both carotid arteries. These birds were then tagged
32
33 109 by means of an orange cable tie placed proximal to the hock, removed from the static shackle
34
35 110 and returned to the space in the main shackle line from which they had been removed. By this
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37 111 time the shackle was within the bleeding area, beyond the automated neck cutter and just
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39 112 beyond the backup slaughterman.
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47
48 114 The treatment birds were stunned by immersing their heads in water in which there was a 50
49
50 115 Hz sinusoidal electric field of 17.5 to 19.0 V/cm rms. The conductivity of the water was
51
52 116 between 1.5 mS/cm and 2.5 mS/cm and the stun was applied for 7 ± 1.5 seconds. This
53
54 117 stunning field strength was shown by Lines *et al.* (2011) to generate immediate and long
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56 118 lasting unconsciousness within one second of application. To prevent the bird's wings from
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58 119 flapping a 36 ± 1.5 mA, 2000 Hz sinusoidal ac current was simultaneously applied through
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1
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3 120 the body of the birds from the shackle to the waterbath. Because both currents are alternating
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5 121 and operating at different frequencies the total current passing through the bird's head was
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8 122 increased by the addition of the second current.
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13 124 Control birds were drawn from the birds passing normally through the plant at the same time.

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15 125 These were stunned using the normal waterbath stunner which was operating at a frequency

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17 126 of 610 Hz using a 30% duty cycle pulse DC waveform with an rms voltage (ac + dc) of 59.3

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19
20 127 V. The average stunning current for these birds, derived by dividing the total current output

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22 128 of the stunner between the 14 birds simultaneously in the waterbath was 63 mA rms (ac + dc)

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24
25 129 per bird. The birds remained in the waterbath for 9.3 s. This stunning current is substantially

26
27 130 below that which will be required by the new EU regulations (EC, 2009)

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32 132 Following automated plucking, evisceration and chilling, and whilst still on the primary
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34 133 processing shackle line, the carcasses of the treatment birds were scored for external quality.

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36 134 A similar score was also taken from the tenth bird on the shackle line following each
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38 135 treatment bird. This bird became part of the (unmatched) control treatment group.

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44 137 The inspection focused on four external quality issues known to be susceptible to stunning
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46 138 damage: engorged wing veins, red wing tips, wing haemorrhages and shoulder haemorrhages.

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48 139 The presence of engorged wing veins was noted (0 or 1) while the other three characteristics
49
50 140 were scored on a scale from 0 (no damage present) to 3 (severe damage), where scores 0 and

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52
53 141 1 represent levels of damage which do not result in carcass downgrading. All external scoring

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55 142 was carried out by the same operator using a subjective comparison against the photographic

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58 143 standards used by Barker (2006). A total of 277 carcasses were scored for each of the

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60 144 treatment and control groups. It was assumed that the 23 treatment carcasses which did not

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3 145 appear at the end of the processing line had been variously rejected by hygiene inspectors,
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5 146 lost from the line or had lost their tags. It was assumed that these carcass were lost at random.
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10 148 At the end of the primary processing line, treatment and control birds were removed from
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12 149 their shackles and placed in storage bins for overnight storage in a chiller at approximately
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14 150 4°C. The next morning at 09:00 the bins were removed from the chillers and taken to a
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16 151 processing room where treatment and control birds were manually portioned and a series of
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18 152 further carcass quality measurements were recorded. Carcass portions were presented for
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20 153 scoring, blinded to treatment. Two hundred and seventy treatment birds and 284 control birds
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22 154 were assessed for internal carcass quality.
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29 156 To assess internal quality, the excised breast muscles were assessed for haemorrhages. The
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31 157 major fillets were assessed as a pair examining both the dorsal and ventral aspect with the
32
33 158 skin removed. The minor fillets were also examined as a pair examining the dorsal aspect.
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35 159 The breast fillets were assessed against the photographic standards used by Barker (2006) and
36
37 160 scored from 0 (no damage) to 3 where scores 0 and 1 do not result in downgrading. The
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39 161 carcasses were also examined for broken bones by checking the pectoral region for the
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41 162 presence of a broken furculum, scapula or coracoid.
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48 164 *Study 2* 49

50 165 During the external inspection of the carcasses from Study 1 it was apparent that treatment
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52 166 carcasses carried a very much higher prevalence of leg damage than control birds. Legs were
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54 167 not included as part of any of the recorded quality assessments because they are not normally
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56 168 vulnerable to damage due to electrical stunning. It appeared that the additional handling
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58 169 received by the treatment birds was causing damage over and above any damage that may
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3 170 have been solely due to the new electrical stunning technique being investigated. The
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6 171 treatment birds received six more handling events than control birds in terms of removal from
7
8 172 shackles and re-shackling. Because of the risk that this extra handling might also have a
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10 173 detrimental effect on other aspects of carcass quality, the treatment protocol was modified
11
12
13 174 and the study repeated using a further 300 treatment birds and 300 control birds over the
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15 175 following two days. The handling of treatment birds was modified by taking the birds directly
16
17 176 from the delivery module trays rather than removing them from the shackle line. Care was
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19
20 177 taken to handle the birds gently and to avoid wing flapping. When vigorous wing flapping did
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22 178 occur in a treatment bird it was recorded (by placing the cable tie tag on the alternate leg).
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25 179 The final change to the protocol was to pay more attention to the depth with which the birds
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27 180 were immersed in the stun bath, endeavouring to ensure that birds were not immersed so
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29
30 181 deeply that their breast muscles were also immersed, as casual observations suggested that
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32 182 this did occur in Study 1.

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36 184 The study was conducted on 300 45 day-old male broilers of average live weight 3.25 kg,
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39 185 sourced from a different farm from those in Study 1. The treated birds were assessed over a
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42 186 period of five hours starting at approximately 08:00 and were subjected to the head-only
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44 187 waterbath stunning treatment. A total of 284 treatment birds and 284 control birds were
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46 188 scored for external carcass quality and 278 treatment birds and 278 control birds scored for
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49 189 internal carcass quality. Birds that were lost from the study were assumed to be missing at
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52 190 random with respect to the experimental treatment. An assessment of external and internal
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54 191 quality was made as for Study 1.

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58 193 *Statistical Analysis*

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3 194 The software package SPSS v16.0 was used for all analyses. As the weight and origin of the
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6 195 birds used for each of the studies differed and the handling associated with the new stunning
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8 196 treatment was altered between studies, the data from Study 1 and Study 2 were analysed
9
10 197 independently. For each study a cross-tabulation of the number of birds in each quality
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12 198 outcome category separated by treatment and control was produced for each quality measure.
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15 199 Each table was tested for an association between the counts in each quality category and
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17 200 treatment by means of a Chi-square test for the binary outcome measures, or by Kendall's
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19 201 tau-b statistic for those with the ordered, four category outcomes. Exact statistics were
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21
22 202 calculated in all cases.
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25 203
26
27 204 Quality measurements with scores of 0 and 1 were considered to have no economic
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29 205 consequence and that scores 2 and 3 would have resulted in downgrading. For these scales
30
31 206 the levels 0 and 1 and 2 and 3 were combined into a binary variable signifying no economic
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33 207 consequence (0) or damage of economic significance (1). In this way all of the outcome
34
35 208 measures become binary outcomes and were subjected to a secondary analysis using a Chi-
36
37 209 square test as described above. As part of this analysis, for all binary outcomes, a lower and
38
39 210 upper confidence interval for the percentage difference in quality defects between the two
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41 211 treatments is also presented.
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48 213 The quality measurements based on records of vigorous wing flapping vigorously in the
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50 214 treatment group were compared with birds in the treatment group that did not flap by means
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52 215 of an exact Mann-Whitney test.
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57 217 **RESULTS**

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3 219 The results for the external quality measures are given in Table 1 as the percentage of birds in
4
5 220 each category for the control and treatment groups in Study 1 and Study 2. The results of the
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8 221 internal quality measures are presented in Table 2.
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10 222
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12 223 No broken scapulae were found and there were only four birds in which both the furculum
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14 224 and coracoid were broken – one bird occurring in each treatment group and in each control
15
16 225 group. Broken bones were therefore scored simply as present or absent (Table 2).
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22 227 The significance tests for the tests of association between each of the quality measures and
23
24 228 treatment are also given in Tables 1 and 2. These indicate there was a difference between
25
26 229 control and treatment in the proportion of red wing tips in Study 1, but not Study 2. There
27
28 230 was a higher proportion of red wing tips in the treatment group than in the control group
29
30 231 (Table 1). There was a smaller proportion of broken bones in the treatment group, but this
31
32 232 only reached significance in Study 2 (Table 2). There was a larger number of poor quality
33
34 233 scores for the major fillet (dorsal) in the treatment group in both Studies 1 and 2 however for
35
36 234 study 2 this was confined to a damage level score of 1 which is not considered to be of
37
38 235 commercial significance. There was a higher number of poor quality scores for the minor
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40 236 fillet (dorsal) in the treatment group in Study 1 but not Study 2.
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48 238 Tests of significance from the exact Chi-square tests for differences in the proportion of
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50 239 commercially significant quality defects between the treatment and control groups, for both
51
52 240 Study 1 and for Study 2, are presented in Table 3 with the 95% confidence interval for the
53
54 241 percentage difference between the two proportions (treatment percentage minus control
55
56 242 percentage). Table 3 indicates that in Study 1 there was a greater proportion of commercially
57
58 243 significant damaged minor fillets (dorsal aspect) in the treatment group ($P = 0.012$, 95%
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3 244 confidence limits +1.9% to +14.4%) and that in Study 2 the new stunning treatment produced
4
5 245 a significantly smaller proportion of carcasses with broken bones ($P = 0.010$, 95% confidence
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7 246 limits -2.1% to -13.7%). No other significant differences were identified between treatment
8
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10 247 and control groups in either study.
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15 249 A comparison of the quality measurements from birds within the treatment group which
16
17 250 displayed vigorous flapping with those that did not, showed that only the wing haemorrhage
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19 251 scores approached a significant difference ($P = 0.071$), with a greater number of high scores
20
21 252 in the flapping group. Of the 284 birds in the treatment group, 40 birds were recorded as
22
23 253 displaying vigorous flapping while still alive. The percentage of birds in each group given
24
25 254 different wing haemorrhage score are shown in Table 4.
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DISCUSSION

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34 258 The most important results of this set of trials are encapsulated in Table 3 which shows the
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36 259 probable changes in economically significant damage as a result of using the head-only
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38 260 stunning treatment. It shows that the application of the head-only stunning technique under
39
40 261 the conditions of Study 1 is likely to have resulted in a small ($8\% \pm 6\%$) increase in the
41
42 262 prevalence of damaged minor breast fillets, but that application of this treatment under the
43
44 263 conditions of Study 2 would not result in an increase in damaged breast fillets but the
45
46 264 prevalence of broken bones would be decreased by $8\% \pm 6\%$.
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54 266 The change in protocol between Study 1 and Study 2 was focused on reducing the amount of
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56 267 extra handling to which the live birds were subjected and on ensuring that the birds' heads
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58 268 were immersed in the stun bath, whilst keeping their breasts clear of contact with the water.
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3 269 Both of these changes mean that Study 2 better reflects the conditions of an effectively setup
4
5 270 and managed automatic shackle line. Despite these changes the birds in Study 2 were still
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7
8 271 handled far more than the control birds which remained on the shackle line throughout the
9
10 272 stunning and slaughter process. It is entirely reasonable therefore to conclude that the
11
12 273 outcome of Study 2 represents the carcass quality that might be achieved if the head-only
13
14 274 stunning system was installed and used on a production shackle line, i.e. a small reduction in
15
16 275 broken bones and no increase in carcass damage.
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22 277 The significance of this small reduction in carcass damage in Study 2 and the small increase
23
24 278 in Study 1 is that they are delivered using a current which has been shown by EEG analysis to
25
26 279 result in immediate and long lasting unconsciousness in a high proportion of the birds (Lines
27
28 280 *et al.*, 2010). The control birds, in contrast, were stunned using a current developed to keep
29
30 281 carcass damage to an acceptable level. It is less than one third that which will be required
31
32 282 under the new EU regulations (EC 2009).
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37
38 284 Barker (2006) compared the carcass damage associated with this typical industry stun current
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40 285 to that resulting from application of the higher currents that will be required in 2013. He
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42 286 found that this would at least double the prevalence of haemorrhagic damage in minor breast
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44 287 fillets from 7% to 17% and increase three-fold the prevalence of major breast fillet damage
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46 288 from 4% to 12%.
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51
52 290 The cost of this damage to the processor can be estimated by assuming that the breast fillets
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54 291 comprise approximately 10% of the bird weight, that damaged fillet meat has a market value
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56 292 of one third that of undamaged fillets and that undamaged fillets have a market value of
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58 293 £3.5/kg. On this basis the increase in damaged fillets results in a cost to the processor of more
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3 294 than £0.05 for each 3 kg broiler that is to be deboned. Each year in the UK over 370 million
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6 295 birds are sold de-boned so the proposed change in stunning currents would result in a cost of
7
8 296 around £18m per year. From an animal welfare point of view, this proposed change could
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10 297 result in a demand for up to 30 million more birds to be slaughtered per year to make up the
11
12 298 short fall of undamaged fillets.

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17 300 The results of both studies therefore represent a very significant improvement in carcass
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19 301 quality compared with that which can be achieved using conventional waterbath stunning for
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21 302 a similar standard of stun.

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26
27 304 Despite the positive result of this quality trial, it is important to understand that this head-
28
29 305 only stunning technique requires significant further development before it can be installed
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31 306 and tested in a commercial plant. In particular, future research must focus on how the amount
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33 307 of power which must be delivered to the waterbath can be reduced without compromising the
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35 308 quality of the stun achieved and on other practical problems that may be encountered in
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37 309 implementing this approach to stunning in a high speed commercial setting.

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42 43 311 **Conclusion and animal welfare implications**

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45
46 312 The most efficient way to improve farm animal welfare is to align the interests of the industry
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48 313 with those of the animal. In traditional electric waterbath stunning the generation of a
49
50 314 reliable, immediate and long lasting stun is associated with an increased risk of carcass
51
52 315 damage so a compromise between the commercial needs of the industry and the needs of the
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54 316 animals has been adopted. The studies reported in this paper have shown that using head-only
55
56 317 waterbath stunning, the quality of the stun applied to the bird need not reduce the quality of
57
58 318 the carcass and that this compromise is not needed.

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3 319 The results show that the carcass damage on birds stunned using a head-only
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5 320 waterbath stunning system is little different from that resulting from normal commercial
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8 321 practice. However the parameters used for the head-only stun have been shown to result in
9
10 322 immediate and long lasting unconsciousness (Lines *et al.*, 2010) whereas the effectiveness of
11
12 323 the commercially used stun parameters are under question and will not be permitted for
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14
15 324 general use in the EU after 2013.

16
17 325 Head-only electrical stunning therefore has the potential to meet simultaneously the
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19 326 commercial requirements of the processing industry for high quality meat and the aspirations
20
21 327 of society for a high standard of animal welfare at slaughter. Significant further development
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23 328 is however needed to implement this approach in a commercial poultry plant.
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384 **Table 1.** Carcass quality assessments of birds from the commercial control (C) or
 385 experimental head-only stunning treatment (T) for two studies. The significance values of
 386 association (P) between the quality measurements and treatment are also given. Where the P
 387 value is less than 0.05 the figures are shown in bold.

388

Study	Treat ment	Engorged Wing Veins			Red Wing Tips, %					Wing Haemorrhage, %					Shoulder Haemorrhage, %				
		n	%	P	0	1	2	3	P	0	1	2	3	P	0	1	2	3	P
1	C	277	12	0.45	78	17	4.3	0.7	0.05	70	20	8.3	2.2	0.54	96	2.2	1.4	0.4	0.11
	T	277	14		85	11	3.6	1.1		74	14	6.9	5.4		98	1.4	0.4	0.0	
2	C	284	7.7	0.65	80	15	4.6	0.4	0.66	81	11	6.3	1.4	0.44	99	0.0	0.7	0.1	1.00
	T	284	9.2		79	16	4.6	1.1		79	13	7.4	0.7		99	0.0	0.4	0.4	

389

390 **Table 2.** *The percentage of birds with broken bones and in each internal carcass quality*
 391 *class from control (C) or experimental head-only stunning treatment (T) from two studies.*
 392 *The significance values of association (P) between the quality measurements and treatment*
 393 *are also given. Where the P value is less than 0.01 the figures are shown in bold.*

Study	Treat ment	n	Broken bones		Major fillets with haemorrhage, %					Major fillets with haemorrhage, %					Minor fillets with haemorrhage, %				
			%	<i>P</i>	Dorsal aspect				Ventral aspect					Dorsal aspect					
					0	1	2	3	<i>P</i>	0	1	2	3	<i>P</i>	0	1	2	3	<i>P</i>
1	C	284	14		70	22	6.3	1.8	0.006	50	37	11	2.1	0.34	21	37	9.9	2.8	<0.001
	T	270	10	0.16	59	31	9.2	1.5		48	34	14	3.7		33	46	17	4.0	
2	C	278	18		83	11	4.0	2.5	0.007	72	22	5.8	0.4	0.62	55	33	9.7	2.5	0.10
	T	278	10	0.01	72	22	3.6	1.8		70	26	3.2	1.4		48	38	12	2.9	

396 **Table 3.** *Statistical significance) from the Chi-square tests of association between the quality*
 397 *measures as binary outcomes for Study 1 and Study 2. The 95 per cent upper (UCI) and*
 398 *lower (LCI) confidence intervals for the percentage difference in damage between the*
 399 *treatment and control are also shown (as treatment % – control %). Where the P value is less*
 400 *than 0.05, figures are shown in bold.*

401

Study		Engorged wing vein	Red wing tip	Wing haem	Shoulder haem	Broken bones	Major dorsal	Major ventral	Minor dorsal
	<i>P</i> value	0.446	1.000	0.593	0.216	0.157	0.312	0.124	0.012
1	UCI	8.1	3.4	7.2	0.5	1.3	7.6	10.9	14.4
	LCI	-3.1	-4.1	-3.5	-3.8	-9.7	-2.3	-1.1	1.9
	<i>P</i> value	0.651	0.852	1.000	1.000	0.010	0.720	0.574	0.533
2	UCI	6.1	4.6	4.9	1.9	-2.1	3.0	2.4	7.9
	LCI	-3.3	-3.1	-4.2	-1.9	-13.7	-5.2	-5.4	-3.5

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4 403 **Table 4.** *The percentage of birds from the treatment group in Study 2 given each of the Wing*
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6 404 *Haemorrhage scores broken down by birds which were or were not recorded as flapping*
7
8 405 *vigorously whilst alive.*
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11 406

Flapping	Wing Haemorrhage Score				
	n	0	1	2	3
No	244	80.3	12.3	7.0	0.4
Yes	40	67.5	20.0	10.0	2.5

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3 **1 Broiler carcass quality using head-only electrical stunning in a waterbath.**
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8 **2**
9 JA Lines¹, SB Wotton², R Barker³, J Spence⁴, L Wilkins² and TG Knowles²
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32 **13 Running title:** Broiler carcass quality using head-only waterbath stunning.
33

34 **14 Keywords:** Animal Welfare, Broiler, Head-only stun, water bath, carcass quality,
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37 haemorrhage
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42 **17 Abstract**
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44 1. The objective was to assess carcass quality of broilers when they were stunned by
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46 immersing their heads in a waterbath with an electric current flowing from one side of it to
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48 the other, while a second small current passed through the body to the waterbath to prevent
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50 involuntary wing flapping.
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53 2. The prevalence of wing, shoulder and breast fillet haemorrhages and of broken bones in the
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55 pectoral region was not greater than that resulting from the normal stunning practice in that
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57 plant (63 mA, 610 Hz pDC).
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3 25 3. These results imply that carcass damage using this technique will be significantly lower
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6 26 than that which will result from the application higher stunning currents required by the new
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8 27 EU slaughter poultry slaughter regulations.
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12 13 14 29 **Introduction**

15
16 30 Eight hundred and thirty million broilers are slaughtered each year in the UK, about three
17
18 31 quarters of which are killed on a shackle line using electrical waterbath stunning (Anon
19
20 32 2007). In traditional waterbath stunning an electric current passes from the waterbath,
21
22 33 through the head, body and legs of the bird, and into the shackle. When suitable electrical
23
24 34 parameters are used, this electric current stuns the bird and immobilises the body. However
25
26 35 the current also causes broken bones and haemorrhagic damage to a proportion of the
27
28 36 carcasses. Since 60% of broilers are sold deboned, this carcass damage is clearly visible to
29
30 37 the purchaser and reduces the value of the meat.
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37 39 Carcass damage prevalence can be reduced by reducing the stunning current used or by
38
39 40 increasing its frequency (Veerkamp and de Vries 1983, Gregory and Wilkins 1989 and
40
41 41 Gregory *et al* 1995) However these changes also decrease the reliability with which the birds
42
43 42 are stunned (Raj *et al* 2006a,b). Selection of the stunning current parameters therefore
44
45 43 requires that the welfare needs of the broilers are balanced against the commercial needs of
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47 44 the processing plant. Not surprisingly this balance is viewed differently by different sections
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49 45 of society.
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56 47 Research by Raj *et al* (2004, 2006a, 2006b) indicates that the electric stunning parameters
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58 48 currently used in the industry (typically 600 Hz Pulsed DC current at 80mA rms per bird) do
59
60 49 not necessarily result in immediate unconsciousness for all birds. New EC regulations on the

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3 50 protection of animals at the time of killing (EC 2009) will, from 2013, require the use of
4
5 51 minimum stunning currents of 100mA for frequencies up to 200 Hz, of 150mA for
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8 52 frequencies of 200-400 Hz and of 200mA for frequencies of 400-1500 Hz. Barker (2006)
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11 53 indicates that these changes are expected to result in significant increases in carcass damage
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13 54 resulting in a cost to the UK industry over £18m and require an additional 30 million birds
14
15 55 provide undamaged fillets.
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20 57 There are indications that head-only electrical stunning results in low levels of carcass
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22 58 damage (Kranen 1996) however, the difficulty of accurately and rapidly applying the
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24 59 electrodes to the birds' heads means that it is currently not suitable for use in high throughput
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26
27 60 commercial plants.
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32 62 Recently, a new concept in head-only stunning was investigated by Lines *et al* (2010), which
33
34 63 doesn't require electrodes to be applied directly to the birds head but rather requires the birds'
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36 64 heads to be dipped into a waterbath which has an electric current flowing across it from one
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39 65 side of the waterbath to the other. This is fundamentally different from the conventional
40
41 66 waterbath where the stunning current runs from the waterbath through the bird's body to the
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43 67 shackles. Since the bird's head does not need to be located and electrodes applied directly,
44
45 68 the approach may be suitable for high-speed application in commercial poultry processing
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48 69 plants. In the investigation, electrical stunning parameters which resulted in immediate and
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50
51 70 prolonged insensibility were identified and a means to prevent the violent involuntary wing
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53 71 flapping which is normally associated with head-only stunning was demonstrated. The
54
55 72 practical significance of this development, however, depends on the effect this approach has
56
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58 73 on carcass quality.
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3 75 In this paper we report on trials which examine the carcass damage in birds stunned using the
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5 76 head-only waterbath stunning technique. The results are compared against control birds
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8 77 which were killed using a normal waterbath stunning system in a commercial processing
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10 78 plant. By referencing these results against the work of Barker (2006), we make a comparison
11
12 79 between the quality results obtained by waterbath head-only stunning, those currently
13
14 80 achieved in a commercial poultry processing plants, and those which would be obtained using
15
16 81 stunning currents recommended by Raj (2006a,b). These are similar to those which will be
17
18 82 mandatory in the EU from 2013 (EC 2009).
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25 84 **Materials and Methods**

26
27 85 Broiler carcass damage measurements were made in two separate but similar studies which
28
29 86 took place on separate days during the same week in the same commercial poultry processing
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31 87 plant.
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36 89 These trials were carried out as a University of Bristol investigation following the approval of the
37
38 90 ethics committee. The stunning methodology that was used had previously been developed and tested
39
40 91 under Home Office licence.
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45 93 ***Study 1***

46
47 94 This study was carried out at a large commercial poultry slaughter plant almost completely
48
49 95 dedicated to slaughtering broiler chickens. Over a period of approximately 5 hours from
50
51 96 08:00, 300 male broilers of 47 days of age and of average live weight 3.49 kg were
52
53 97 individually removed from the shackle line post hang-on but before the stun bath. They were
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55 98 transferred to a single shackle suspended on a rope and, when settled, their heads were
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57 99 lowered smoothly into the experimental head-only waterbath stunner. Each bird was
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3 100 subjected to an electrical stun and then immediately transferred to a second shackle on an
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5 101 adjacent fixed frame where an experienced slaughterman employed at the poultry plant cut its
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8 102 neck manually, with the aim of severing both carotid arteries. These birds were then tagged
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10
11 103 by means of an orange cable tie placed proximal to the hock, removed from the static shackle
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13 104 and returned to the space in the main processing plant shackle line from which they had been
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15 105 removed. By this time this shackle was within the bleeding area, beyond the automated neck
16
17 106 cutter and just beyond the backup slaughterman.
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21
22 108 The treatment birds were stunned by immersing their heads in water in which there was a 50
23
24 109 Hz sinusoidal electric field of 17.5 to 19 V/cm rms. The conductivity of the water was
25
26
27 110 between 1.5 mS/cm and 2.5 mS/cm and the stun was applied for 7 ± 1.5 seconds. This
28
29 111 stunning field strength was shown by Lines *et al* (2010) to generate immediate and long
30
31 112 lasting unconsciousness within one second of application. To prevent the bird's wings
32
33
34 113 flapping a 36 ± 1.5 mA, 2000 Hz sinusoidal ac current was simultaneously applied through
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36 114 the birds' body from shackle to waterbath. Because both currents are alternating and
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39 115 operating at different frequencies the total current passing through the birds head is increased
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41 116 by the additional of this second current.
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46 118 Control birds were drawn from the birds passing normally through the plant at the same time.
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48 119 These were stunned using the normal waterbath stunner which was operating at a frequency
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51 120 of 610 Hz using a 30% duty cycle pulse DC waveform with an rms voltage (ac + dc) of 59.3
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53 121 V. The average stunning current for these birds, derived by dividing the total current output
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55 122 of the stunner between the 14 birds simultaneously in the waterbath was 63mA rms (ac + dc)
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57
58 123 per bird. The birds remained in the waterbath for 9.3 seconds. This stunning current is
59
60 124 substantially below that which will be required by the new EU regulations (EC 2009)

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126 Following automated plucking, evisceration and chilling, and whilst still on the primary
127 processing shackle line, the carcasses of the treatment birds were scored for external quality.

128 A similar score was also taken from the tenth bird on the shackle line following each
129 treatment bird. This bird became part of the (unmatched) control treatment group.

130

131 The inspection focused on four external quality issues known to be susceptible to stunning
132 damage: engorged wing veins, red wing tips, wing haemorrhages and shoulder haemorrhages.

133 The presence of engorged wing veins was noted (0 or 1) while the other three characteristics
134 were scored on a scale from 0 (no damage present) to 3 (severe damage), where scores 0 and
135 1 represent levels of damage which do not result in carcass downgrading. All external scoring
136 was carried out by the same operator using a subjective comparison against photographic
137 standards. These were the same standards as used by Barker (2006). A total of 277 carcasses
138 were scored for each of the treatment and control groups. It was assumed that the 23
139 treatment carcasses which did not appear at the end of the processing line had been variously
140 rejected by hygiene inspectors lost from the line or had lost their tags. It was assumed that
141 these losses were 'missing completely at random'.

142

143 At the end of the primary processing line, treatment and control birds were removed from
144 their shackles and placed in storage bins for overnight storage within a chiller at
145 approximately 4°C. The next morning at 09:00 the bins were removed from the chillers and
146 taken to a processing room where treatment and control birds were manually portioned and a
147 series of further carcass quality measurements were recorded. Carcass portions were
148 presented for scoring, blinded to treatment. Two hundred and seventy treatment birds and 284
149 control birds were assessed for internal carcass quality.

150

151 To assess internal quality, the excised breast muscles were assessed for haemorrhages. The
152 major fillets were assessed as a pair examining both the dorsal and ventral aspect with the
153 skin removed. The minor fillets were also examined as a pair examining the dorsal aspect.
154 The breast fillets were again assessed against the photographic standards used by Barker
155 (2006) and scored from 0 (no damage) to 3 where scores 0 and 1 do not result in
156 downgrading. The carcasses were also examined for broken bones by checking the pectoral
157 region for the presence of a broken furculum, scapula or coracoid.

158

159 *Study 2*

160 During the external inspection of the carcasses from Study 1 it was apparent that treatment
161 carcasses carried a very much higher prevalence of leg damage than control birds. Legs were
162 not included as part of any of the recorded quality assessments because they are not normally
163 vulnerable to damage due to electrical stunning. It appeared that the additional handling
164 received by the treatment birds was causing damage over and above any damage that may
165 have been solely due to the new electrical stunning technique being investigated. The
166 treatment birds received six more handling events than control birds in terms of removal from
167 shackles and re-shackling. Because of the risk that this extra handling might also have a
168 detrimental effect on other aspects of carcass quality, the treatment protocol was modified
169 and the study repeated using a further 300 treatment birds and 300 control birds over the
170 following two days. The handling of treatment birds was modified by taking the birds directly
171 from the delivery module trays rather than removing them from the shackle line. Care was
172 taken to handle the birds gently and to avoid wing flapping. When vigorous wing flapping did
173 occur in a treatment bird it was recorded (by placing the cable tie tag on the alternate leg).
174 The final change to the protocol was to pay more attention to the depth with which the birds

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3 175 were immersed in the stun bath, endeavouring to ensure that birds were not immersed so
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6 176 deeply that their breast muscles were also immersed. Casual observations had suggested that
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8 177 this was occurring in Study 1.
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13 179 In this second study which ran over a period of five hours starting at approximately 08:00,
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15 180 300 45 day-old, male broilers of average live weight 3.25 kg, sourced from a different farm
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17 181 from those in Study 1 were subjected to the head-only waterbath stunning treatment. A total
18
19 182 of 284 treatment birds and 284 control birds were scored for external carcass quality and 278
20
21 183 treatment birds and 278 control birds scored for internal carcass quality. Birds that were lost
22
23 184 from the study were assumed to be 'missing completely at random'. An assessment of
24
25 185 external and internal quality was made as for Study 1.
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30 31 187 *Statistical Analysis*

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34 188 The software package SPSS v16.0 was used for all analyses. As the weight and origin of the
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36 189 birds used for each of the studies differed and the handling associated with the new stunning
37
38 190 treatment was altered between studies, the data from Study 1 and Study 2 were analysed
39
40 191 independently. For each study a cross-tabulation of the number of birds in each quality
41
42 192 outcome category broken down by treatment and control was produced for each quality
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44 193 measure. Each table was tested for an association between the counts in each quality category
45
46 194 and treatment by means of a Chi-square test, for the binary outcome measures, or by
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48 195 Kendall's tau-b statistic for those with the ordered, four category outcomes. Exact statistics
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50 196 were calculated in all cases.
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58 198 For all the quality measurements which were made on a scale of 0 to 3, levels 0 and 1 are
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60 199 considered to have no economic consequence but levels 2 and 3 will result in downgrading.

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3 200 For these scales the levels 0 and 1 and 2 and 3 were collapsed to give a binary variable
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6 201 signifying no economic consequence (0) or damage of economic consequence (1). In this way
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8 202 all of the outcome measures become binary outcomes and were then subjected to a secondary
9
10 203 analysis using a Chi-square test as described above. As part of this analysis, for all binary
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12 204 outcomes, a lower and upper confidence interval for the percentage difference in quality
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14 205 defects between the two treatments is also presented.
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20 207 The quality measurements made on birds recorded as flapping vigorously within the
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22 208 treatment group were compared with birds in the treatment group that did not flap by means
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24 209 of an exact Mann-Whitney test.
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27 210

28 29 211 **Results**

30
31 212 The results for the external quality measures are given below in Table 1 as the percentage of
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33 213 birds within each score category for the control and treatment groups broken down by Study
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35 214 1 and Study 2. The results of the internal quality measures are similarly given in Table 2.
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41 216 No broken scapulae were found and there were only four birds in which both the furculum
42
43 217 and coracoid were broken – one bird occurring in each treatment group and in each control
44
45 218 group. Broken bones were therefore scored simply as present or absent (Table 2).
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49
50 220 The P values from the tests of association between each of the full scale quality measures and
51
52 221 treatment are also given in Tables 1 and 2. These indicate there was a difference between
53
54 222 control and treatment in the proportion of Red Wing Tips in Study 1, but not Study 2. There
55
56 223 was a greater proportion of Red Wing Tips in the treatment group than in the control group
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58 224 (Table 1). There was a smaller proportion of broken bones in the treatment group, but this
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3 225 only reached significance within Study 2. There was a greater number of poor quality scores
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5
6 226 for the major fillet (dorsal) in the treatment group within both Studies 1 and 2 however for
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8 227 study 2 this was confined to damage level 1 scores which are not considered to be of
9
10 228 commercial significance. There was a greater number of poor quality scores for the minor
11
12 229 fillet (dorsal) within the treatment group, but only within Study 1.

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14
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16
17 231 Table 3 shows the P values from the exact Chi-square tests for differences in the proportion
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19 232 of commercially significant quality defects between the treatment and control groups, for
20
21 233 both Study 1 and for Study 2. Also shown is a 95% confidence interval for the percentage
22
23 234 difference between the two proportions (treatment percentage minus control percentage).
24
25 235 This table indicates that in Study 1 there was a greater proportion of commercially significant
26
27 236 damaged minor fillets (dorsal aspect) in the treatment group ($P = 0.012$, 95% confidence
28
29 237 limits +1.9% to +14.4%) and that in Study 2 the new stunning treatment produced a
30
31 238 significantly smaller proportion of carcasses with broken bones ($P = 0.010$, 95% confidence
32
33 239 limits -2.1% to -13.7%). No other significant differences were identified between treatment
34
35 240 and control groups within either Study 1 or Study 2.

36 241

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39 242 A comparison of the quality measurements from birds within the treatment group which
40
41 243 displayed vigorous flapping with those that did not, showed that only the wing haemorrhage
42
43 244 scores approached a significant difference ($P = 0.071$), with a greater number of high scores
44
45 245 in the flapping group. Of the 284 birds in the treatment group 40 birds were recorded as
46
47 246 displaying vigorous flapping whilst still alive. The percentage of birds within each group
48
49 247 given each wing haemorrhage score are shown in Table 4.

50 248

51 249 **Discussion**

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3 250 The most important results of this set of trials are encapsulated in Table 3 which shows the
4
5 251 probable changes in economically significant damage as a result of using the head-only
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7
8 252 stunning treatment. It shows that the application of this head-only stunning technique under
9
10 253 the conditions of Study 1 is likely to have resulted in a small ($8\% \pm 6\%$) increase in the
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12 254 prevalence of damaged minor breast fillets, but that application of this treatment under the
13
14
15 255 conditions of Study 2 would not result in this increase, but rather only result in a decrease in
16
17 256 the prevalence of broken bones by $8\% \pm 6\%$.

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22 258 The change in protocol between Study 1 and Study 2 was focused on reducing the amount of
23
24 259 extra handling to which the live birds were subjected and on ensuring that the birds' heads
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27 260 were immersed in the stun bath, whilst keeping their breasts clear of contact with the water.
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29 261 Both of these changes mean that Study 2 better reflects the conditions of an effectively setup
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31 262 and managed automatic shackle line. Despite these changes the birds in Study 2 were still
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33 263 handled far more than the control birds which remained on the shackle line throughout the
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35 264 stunning and slaughter process. It is entirely reasonable therefore to conclude that the
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37 265 outcome of Study 2 represents the carcass quality that might be achieved if this head-only
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39 266 stunning system was installed and used on a production shackle line, ie that a small reduction
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41 267 in broken bones and no increase in other damage is likely to be the quality outcome of such a
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43 268 development.

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50 270 The significance of this small reduction in carcass damage in Study 2 and the small increase
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52 271 in Study 1 is that they are delivered using a current which has been shown by EEG analysis to
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54 272 result in immediate and long lasting unconsciousness in a high proportion of the birds (Lines
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56 273 *et al* 2010). The control birds, in contrast, were stunned using a current developed to keep
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3 274 carcass damage to an acceptable level. It is less than one third that which will be required
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6 275 under the new EU regulations (EC 2009).

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10 277 Barker (2006) compared the carcass damage associated with this typical industry stun current
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12 278 to that resulting from application of the higher currents which will be required in 2013. He
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15 279 found this would at least double the prevalence of haemorrhagic damage in minor breast
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17 280 fillets from 7% to 17% and increase three-fold the prevalence of major breast fillet damage
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19 281 from 4% to 12%.

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24 283 The cost of this damage to the processor can be estimated by assuming that the breast fillets
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26 284 comprise approximately 10% of the bird weight, that damaged fillet meat has a market value
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28 285 of one third that of undamaged fillets and that undamaged fillets have a market value of
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30 286 £3.5/kg. On this basis the increase in damaged fillets results in a cost to the processor of more
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32 287 than £0.05 for each 3kg broiler that is to be deboned. Each year in the UK over 370 million
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34 288 birds are sold de-boned so the proposed change in stunning currents would result in a cost of
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36 289 around £18m per year. From an animal welfare point of view, this proposed change could
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38 290 result in a demand for up to 30 million more birds to be slaughtered per year to make up the
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40 291 short fall of undamaged fillets.

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46 293 The results of both studies therefore represent a very significant improvement in carcass
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48 294 quality compared with that which can be achieved using conventional waterbath stunning for
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50 295 a similar standard of stun.

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56 297 Despite the positive result of this quality trial, it is important to understand that this head-
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58 298 only stunning technique requires significant further development before it can be installed
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3 299 and tested in a commercial plant. In particular, future research must focus on how the amount
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5 300 of power which must be delivered to the waterbath can be reduced without compromising the
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8 301 quality of the stun achieved and on other practical problems which may be encountered in
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10 302 implementing this approach to stunning in a high speed commercial setting.
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14 15 304 **Conclusion and animal welfare implications**

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17 305 The most efficient way to improve farm animal welfare is to align the interests of the industry
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19 306 with those of the animal. In traditional electric waterbath stunning the generation of a
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21 307 reliable, immediate and long lasting stun is associated with an increased risk of carcass
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23 308 damage so a compromise between the commercial needs of the industry and the needs of the
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25 309 animals has been found. The studies reported in this paper have shown that using head-only
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27 310 waterbath stunning, the quality of the stun applied to the bird need not reduce the quality of
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29 311 the carcass so this compromise is not needed.
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36 313 The results show that the carcass damage on birds stunned using a head-only waterbath
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38 314 stunning system is little different from that resulting from normal current commercial
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40 315 practice. However the parameters used for the head-only stun have been shown to result in
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42 316 immediate and long lasting unconsciousness (Lines *et al* 2010) whereas the effectiveness of
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44 317 the commercially used stun parameters are under question and will not be permitted for
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46 318 general use in the EU after 2013.
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53 320 Head-only electric stunning therefore has the potential to meet simultaneously the
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55 321 commercial requirements of the processing industry for high quality meat and the aspirations
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57 322 of society for a high standard of animal welfare at slaughter. Significant further development
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59 323 is however needed to implement this approach in a commercial poultry plant.
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6 325 **Acknowledgements**
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11
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377 **Table 1** The percentage of birds from the control (C) or treatment (T) group with engorged
 378 wing veins and within each external carcass quality class (0 – 3), broken down by Study.
 379 Class 0 indicates no visible damage and class 1 indicates a low level of damage which will
 380 not result in downgrading while classes 2 and 3 indicate damage which will result in carcass
 381 downgrading (Barker 2006). The *P* values of association between the quality measurements
 382 and treatment from the exact Chi-square test (Engorged wing veins) and exact Kendall's tau-
 383 b test (remaining measures) are also given. Where the *P* value is less than 0.1 the figures are
 384 shown in bold.

		Engorged Wing Veins			% Birds with Red Wing Tips					% Birds with Wing Haemorrhage					% Birds with Shoulder Haemorrhage				
		n	%	<i>P</i>	0	1	2	3	<i>P</i>	0	1	2	3	<i>P</i>	0	1	2	3	<i>P</i>
Study 1	C	277	12	0.45	78	17	4.3	0.7	0.05	70	20	8.3	2.2	0.54	96	2.2	1.4	0.4	0.11
	T	277	14		85	11	3.6	1.1		74	14	6.9	5.4		98	1.4	0.4	0.0	
Study 2	C	284	7.7	0.65	80	15	4.6	0.4	0.66	81	11	6.3	1.4	0.44	99	0.0	0.7	0.1	1.00
	T	284	9.2		79	16	4.6	1.1		79	13	7.4	0.7		99	0.0	0.4	0.4	

Table 2 The percentage of birds from the control (C) or treatment (T) group with broken bones and within each internal carcass quality class (0 – 3), broken down by Study. Class 0 indicates no visible damage and class 1 indicates a low level of damage which will not result in downgrading while classes 2 and 3 indicate damage which will result in carcass downgrading (Barker 2006). The *P* values of association between the quality measurements and treatment from the exact Chi-square test (broken bones) and exact Kendall's tau-b test (remaining measures) are also given. Where the *P* value is less than 0.1 the figures are shown in bold.

		broken bones			% Major Fillets with Haemorrhage (dorsal aspect)					% Major Fillets with Haemorrhage (ventral aspect)					% Minor Fillets with Haemorrhage (dorsal aspect)				
		n	%	<i>P</i>	0	1	2	3	<i>P</i>	0	1	2	3	<i>P</i>	0	1	2	3	<i>P</i>
Study 1	C	284	14	0.16	70	22	6.3	1.8	0.006	50	37	11	2.1	0.34	21	37	9.9	2.8	<.001
	T	270	10		59	31	9.2	1.5		48	34	14	3.7		33	46	17	4.0	
Study 2	C	278	18	0.01	83	11	4.0	2.5	0.007	72	22	5.8	0.4	0.62	55	33	9.7	2.5	0.10
	T	278	10		72	22	3.6	1.8		70	26	3.2	1.4		48	38	12	2.9	

397 **Table 3** The *P* values (statistical significance) from the Chi-square tests of association
 398 between the quality measures as binary outcomes broken down by Study 1 and Study 2. The
 399 95 per cent upper (UCI) and lower (LCI) confidence intervals for the percentage difference in
 400 damage between the treatment and control are also shown (as treatment % – control %).
 401 Where the *P* value is less than 0.1, figures are shown in bold.

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		Engorged wing vein	Red wing tip	Wing haem	Shoulder haem	Broken bones	Major dorsal	Major ventral	Minor dorsal
	<i>P</i> value	0.446	1.000	0.593	0.216	0.157	0.312	0.124	0.012
Study 1	UCI	8.1	3.4	7.2	0.5	1.3	7.6	10.9	14.4
	LCI	-3.1	-4.1	-3.5	-3.8	-9.7	-2.3	-1.1	1.9
	<i>P</i> value	0.651	0.852	1.000	1.000	0.010	0.720	0.574	0.533
Study 2	UCI	6.1	4.6	4.9	1.9	-2.1	3.0	2.4	7.9
	LCI	-3.3	-3.1	-4.2	-1.9	-13.7	-5.2	-5.4	-3.5

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4 404 **Table 4** The percentage of birds from the treatment group in Study 2 given each of the Wing
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6 405 Haemorrhage scores broken down by birds which were or were not recorded as flapping
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8 406 vigorously whilst alive.
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	n	Wing Haemorrhage Score			
		0	1	2	3
Not Flapping	244	80.3	12.3	7.0	0.4
Flapping	40	67.5	20.0	10.0	2.5

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