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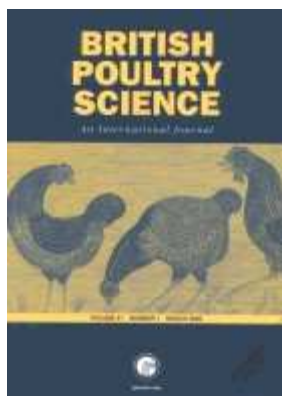
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1 **Head-only electrical stunning of poultry using a waterbath: a feasibility study**

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3
4 25 **Abstract** 1. The objective of this work was to investigate the feasibility of head only
5
6 26 waterbath stunning as a means of generating immediate and long lasting unconsciousness
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8 27 while preventing wing flapping and so avoiding carcass damage.
9
10 28 2. EEG measurements showed that immersion of the heads of the broilers for one second in a
11
12 29 waterbath containing water of conductivity 2.5 mS/cm and a 50 Hz electric field of 10 V/cm
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14 30 resulted in immediate unconsciousness, and that increasing the electric field strength
15
16 31 extended the duration of unconsciousness.
17
18 32 3. The passage of a 25 – 30 mA alternating current of frequency 2000 Hz through the
19
20 33 broilers' bodies suppressed the wing flapping that followed a stun.
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22 34 4. When the body current and electric field were applied simultaneously, wing flapping was
23
24 35 prevented and EEG signals were suppressed for over 30 seconds indicating that the
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26 36 immediate unconsciousness was lasted long enough to facilitate humane slaughter.
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34 INTRODUCTION

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36 39 In conventional electric waterbath stunning an electric current is passed from the waterbath
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38 40 through the head, body and legs of each bird to stun it. To protect the birds' welfare, the
41
42 41 current must be large enough to achieve immediate and long lasting unconsciousness. The
43
44 42 skeletal muscle contractions caused by the current passing through the bodies of the birds
45
46 43 result in a high prevalence of carcass damage so processors are under financial pressure to
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48 44 use lower currents, potentially compromising welfare.
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55 47 Commonly used stunning parameters in the UK industry are 600 Hz pulsed dc current at
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57 48 about 80mA root mean square (rms) per bird. However due to concern that parameters such
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59 49 as these might not result in immediate unconsciousness for all birds, the Council of the
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3 50 European Union has adopted new regulations requiring the use of larger stunning currents
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5 51 from 2013 (EC 2009). Barker (2006) has examined parameter sets very similar to those
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7
8 52 which will be required and shown that they are likely to result in a large increase in carcass
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10 53 damage.

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15 55 An alternative approach to slaughtering poultry is the use of controlled atmosphere stunning
16
17 56 (CAS). Properly applied controlled atmosphere systems may result in high welfare standards
18
19 57 and high levels of carcass quality (McKeegan *et al* 2006, 2007, Abeyesinghe *et al* 2007).
20
21 58 However because of the high installation and operating costs, it is unlikely to be
22
23 59 economically viable for medium and small processing plants in the near future.
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29 61 Electrical stunning, where the current is passed across the head of the bird avoiding the body,
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31 62 can result in a high quality stun without compromising carcass quality since the stunning
32
33 63 current does not cause skeletal muscle contractions in the body (Raj *et al.*, 2001, Raj &
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35 64 O'Callaghan 2004). However application of head-only stunning in a high throughput line is
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37 65 currently not possible due to the need to accurately locate and place electrodes on the head of
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39 66 every bird.
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46 68 Over the last few years there has been a substantial amount of research and development in
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48 69 equipment to electrically stun farmed fish in water (Lines *et al* 2003, 2004, 2005, Robb *et al*
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50 70 2001, Roth *et al* 2003, 2004, Lambooij *et al* 2008). This stunning method differs from that
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52 71 used for poultry in that both electrodes are submerged in the water and electric current flows
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54 72 continuously between them. Some of this current also passes through any fish that are in the
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56 73 water without the need to make any other further physical contact with them.
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3 75 In this paper we report on trials which apply this stunning technique to poultry. The birds are
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5 76 restrained in a conventional shackle by their legs and their heads are dipped into a waterbath
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8 77 to stun them. The electric current used to stun the birds is not passed through their bodies but
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10 78 rather passes from one side of the waterbath to the other. Some of this current also passes
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12 79 through the head, achieving a head-only stun without the need to locate the head accurately.
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17 81 This novel approach to stunning broiler chickens results in the requirement for more
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19 82 electrical power and requires a different approach to describe the electrical characteristics of
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21 83 the stun. More electrical power is required because the head of the bird occupies a relatively
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23 84 small part of the cross-sectional area of the tank and therefore intercepts only a small part of
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25 85 the electrical current that passes through the tank. A different approach to characterising the
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27 86 electrical characteristics of the stun is required because it is neither practical nor necessary to
28
29 87 measure the current passing through the head of the bird. The most appropriate measurement
30
31 88 is the electric field (or voltage gradient) in the water. In this paper this is specified in terms of
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33 89 volts per centimetre (V/cm). The current density (A/cm^2) in the water could also be used as a
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35 90 descriptor but it is very sensitive to changes in water conductivity and for any given water
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37 91 conductivity is directly proportional to the electric field (Lines & Kestin 2004).
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46 93 Intense wing flapping is normally observed when a chicken is killed by neck dislocation or
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48 94 following an effective percussive or head-only electrical stun. If left unchecked this wing
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50 95 flapping can result in broken or dislocated wings. However, body immobilisation can be
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52 96 produced using currents far lower than that required to stun the birds. In this research we
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54 97 investigate the use of a small high frequency current passing through the body to prevent
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56 98 wing flapping during head-only waterbath stunning.
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3 100 The criteria for humane electrical stunning and slaughter used in this work are that the birds
4
5 101 lose sensibility immediately and that they remain insensible until they are dead. To
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8 102 demonstrate this, the electrical stun parameters are tested using only a short (1 second)
9
10 103 exposure. This exposure is required to result in epileptiform brain activity followed by a
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12 104 period of suppressed electroencephalogram (EEG) activity which is maintained until at least
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14 105 30s after the end of the stun application. The epileptiform activity and subsequent period of
15
16 106 suppressed EEG activity is considered indicative of unconsciousness. A 30 s duration of
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18 107 suppression is recommended by Schütt-Abraham *et al* (1983) and is supported by data from
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20 108 Raj *et al.* (2006a) which indicates that EEG activity in broilers becomes suppressed by blood
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22 109 loss within 25 s of a full ventral neck cut.
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29 111 The aim of the work is to determine the electrical parameters required to generate immediate
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31 112 and sustained unconsciousness using head only waterbath stunning and to determine the
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33 113 electrical parameters required to prevent involuntary wing flapping during stunning.
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38 39 115 **MATERIALS AND METHODS**

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43 117 The electrical stunning waterbath used in this study was 16 cm x 16 cm x 12 cm deep.
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45 118 Stainless steel sheet electrodes (16 cm x 12 cm) were fixed on two opposing sides of the tank.
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48 119 A tank insert was also used to enable the distance between the electrodes to be reduced from
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50 120 16 cm to 12 cm enabling higher electric field strengths to be achieved. The tank was filled
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52 121 with water with a conductivity which was maintained between 1.5 and 2.5 mS/cm. An
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54 122 electric field was generated in the water by applying a 50 Hz sinusoidal voltage difference to
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56 123 the electrodes.
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3 125 In all the experiments, unless specified, individual birds were suspended from a conventional
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5 126 metal shackle which was lowered to immerse the bird's head in the water while using a noose
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7
8 127 to control the position of its head. The birds were then exposed for one second to a pre-
9
10 128 determined electric field in the water. All voltages and currents quoted in this paper refer to
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12
13 129 root mean square (rms) values.

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17 131 Parts of this investigation were carried out under Home Office licence and the remainder as a
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20 132 University Investigation following the approval of the local ethics committee. The broilers
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22 133 were obtained from local commercial farms.

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27 135 Four separate experiments were performed:

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29 136 Experiment 1 was designed to identify the electric field in the waterbath needed to produce
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31 137 immediate unconsciousness. An initial indication of the field strength required was gained
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34 138 using behavioural observations of the birds. The findings were then refined by recording and
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36 139 analysing EEG signals from implanted electrodes. Broilers of average weight 2.2 ± 0.3 kg
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39 140 and about 42 days of age were exposed for one second to a 50 Hz sinusoidal electric field by
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41 141 immersing their heads in the waterbath. Electric field strengths of 7.5 to 10 V/cm rms were
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43 142 used for the initial behavioural studies and 10 to 25 V/cm rms for the EEG signal analysis.
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46 143 The number of birds used for each condition are given in Tables 1 and 2.

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51 145 The behavioural signs of unconsciousness were the presence of immediate wing flapping, the
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53 146 absence of rhythmic breathing for at least eight seconds post stun and the loss of neck tension
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55 147 (Gregory & Wotton, 1990). When birds were considered to be stunned the time to the return
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58 148 of breathing and neck tension were recorded: they were then killed by dislocation of the neck.

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3 150 The birds used for the EEG analysis were implanted with electrodes for EEG recording. The
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5 151 implantation procedure was described by Raj *et al* (2006a). The birds were exposed to
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7
8 152 electric fields ranging from 10 to 25 V/cm. The spontaneous EEG signals were recorded for
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10 153 two minutes before and for up to two minutes after the treatment and examined for evidence
11
12 154 of epileptiform activity and EEG suppression. The presence of high amplitude spikes at
13
14 155 frequencies between 3 and 8 Hz was regarded as epileptiform activity. The recorded signals
15
16 156 were also analysed to determine the change in the total power content of the EEGs in the 2 to
17
18 157 30Hz band before and after stunning, as described by Raj *et al.* (2006a). A reduction in power
19
20 158 in three consecutive one second epochs to less than 10% of the pre-stun value was considered
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22 159 to be indicative of EEG suppression (Raj & O'Callaghan, 2004). The total duration of the
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24 160 epileptiform EEG and subsequent suppression was determined for each broiler as an indicator
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26 161 of the duration of unconsciousness induced by the treatment.
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34 163 Experiment 2 was designed to determine the amplitude of the current through the birds'
35
36 164 bodies that was required to suppress wing flapping following a stun. Twenty broilers of
37
38 165 average weight 2.2 ± 0.3 kg were used in this experiment. Each bird was hung on a shackle
39
40 166 and killed using a pneumatic percussive poultry killer applied to the frontal bone. This
41
42 167 induced severe wing flapping. The bird's head was then immediately lowered into the
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44 168 waterbath. No electric field existed across the waterbath but a voltage difference between the
45
46 169 shackle and the waterbath generated an electric current through the body of the birds. The
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48 170 current was varied in both frequency and amplitude. Electric currents were 14-19 mA at
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50 171 50Hz, (4 birds), 18-21 mA at 1000 Hz (three birds), 15-25 mA at 1500 Hz (four birds) 17-31
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52 172 mA at 2000 Hz (six birds) and 35-47 mA at 3900 Hz (three birds). Assessment of suppression
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54 173 of the flapping was somewhat subjective but, as a guide, it was considered to be suppressed if
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56 174 the movement of the wing tips of more than about 10 cm was prevented.
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6 176 Experiment 3 investigated the combined effect on the EEG of the stun field and body current
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8 177 to ensure that the immobilisation current passing through the body did not reduce the efficacy
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10 178 of the head-only stun. Although we had no reason to expect such a reduction to occur we
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12 179 adopted a cautious position in order to safeguard the welfare of the birds. Nine birds were
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14 180 implanted with EEG recording electrodes as described above. After overnight recovery, they
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16 181 were individually hung on a shackle and exposed to a 50 Hz ac electric field of 20 V/cm as
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18 182 described in experiment 1, and simultaneously to a 2000 Hz ac body immobilisation current
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20 183 of 19 ± 0.4 mA. The EEGs were recorded and analysed as described under Experiment 1. The
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22 184 broilers were killed using a Schedule 1 method.
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29 186 Experiment 4 was designed to replicate the processes of stunning and killing broilers in a
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31 187 commercial processing plant to ensure that wing flapping was controlled following removal
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33 188 of the birds from the waterbath. A total of 21 broilers of average body weight 2.2 ± 0.2 kg
34
35 189 were used. The birds were hung on the shackle and their heads lowered into the waterbath.
36
37 190 Each bird was exposed to a 50 Hz electric field of 20 V/cm rms across the head and
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39 191 simultaneously a 2000 Hz ac immobilisation current of $32 \text{ mA} \pm 4 \text{ mA}$. A noose was not
40
41 192 needed to control the head because of the immobilisation current applied to the body. These
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43 193 currents were applied for either 5 s (16 birds) or 10 s (five birds). A ventral neck cut aimed at
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45 194 severing two carotid arteries and two jugular veins was performed within five seconds of the
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47 195 end of stunning and the birds were observed until the end of bleeding for the occurrence of
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49 196 wing movements as an indication of the diminishing effect of the treatments.
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58 198 **Statistical Analyses**
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3 199 Linear regression statistics were used and we report overall confidence intervals for
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5 200 proportions of birds stunned as assessed by behavioural observation and EEG using Wilson's
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8 201 Method as described in Altman *et al* (2000))
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RESULTS

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17 205 The results of Experiment 1 are given in Tables 1 and 2. The behavioural observations
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19 206 indicated that electric field strength of 10 V/cm was required to reliably induce seizures. A
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22 207 regression analysis did not identify a relationship between the electric field in the water and
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24 208 time to the return of breathing ($P > 0.45$) or neck tension ($P > 0.34$), whether corrected for
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27 209 live weight or not.
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31 211 Examination of the EEG signals for the implanted birds (Table 2) showed that exposure of
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33 212 broilers to an electric field of 10 V/cm rms resulted in epileptiform activity but that EEG
34
35 213 levels were not suppressed after the end of the epileptiform activity. Exposure to higher
36
37 214 electric field strengths resulted in both epileptiform activity and EEG suppression to less than
38
39 215 10% of pre-stun values for an extended period in all the birds. Sample EEG time histories are
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41
42 216 given in Figure 1.
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48 218 The results in Table 2 indicate that an increase in the duration of EEG suppression is
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50 219 associated with each increase in electric field strength. This suggests that an increase in the
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52 220 field strength increases the duration of unconsciousness, however due to the small sample
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55 221 size, this observation has a low statistical significance ($P = 0.27$).
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3 223 The results of Experiment 2 are shown in Figure 2. Broilers in which wing flapping was
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5 224 suppressed are indicated with solid markers whereas birds in which wing flapping was not
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8 225 adequately suppressed are indicated with open markers. The results suggest that the current
9
10 226 required to suppress wing flapping increases as the frequency of the current is increased and
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12 227 that wing flapping is likely to be prevented by the use of a 2000 Hz current of 25 - 30 mA. It
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14
15 228 is possible that the current needed to suppress wing flapping varies with bird size however
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17 229 this was not investigated.

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22 231 In Experiment 3, some of the EEG signals were not readable due to technical problems.
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24 232 Epileptiform EEG was readable in five out of nine cases and there was no indication in the
25
26 233 other EEG signals that epileptiform activity did not occur. An estimate of the duration of
27
28 234 EEG suppression was possible in four out of ten signals. In these birds the epileptiform
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30 235 activity lasted 10 ± 0.5 s and the EEG total power content remained at less than 10% of pre-
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32 236 exposure values until 32 ± 3 s post stun.

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38 238 In Experiment 4, the simultaneous and extended application of an electric field to the head,
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40 239 and immobilisation current to the body, followed by ventral neck cutting within five seconds
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42 240 resulted in rapid death as defined by Raj *et al.* (2006a,b,c). All the birds exhibited twitching
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44 241 in the wingtips between 55 and 60 seconds after neck cutting when bleeding had stopped but
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46 242 wing flapping did not occur after removal from the waterbath following exposures of either
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48 243 five or ten seconds.

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54 245 In the combined data from Experiments 1, 3 and 4, stunning was verified by behavioural
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56 246 and/or EEG measures in 53 out of 53 birds (15+17+10+21) that were stunned using an
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58 247 electric field of 10 V/cm or more. This gives a confidence interval for the percentage of

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3 248 stunned birds of between 93.2 to 100 per cent. Analysis of the combined data from 15 birds
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5 249 (7+3+1+4) in Experiments 1 and 3 produced a confidence interval of 79.6 to 100 per cent of
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8 250 birds demonstrating EEG suppression following epileptiform activity when a field of 15V/cm
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10 251 or greater was used.
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DISCUSSION

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16 256 Comparisons of the behavioural indicators of unconsciousness and the EEG results showed
17 257 that the times to resumption of breathing (22s) and neck muscle tone (42s) in broilers
18 258 exposed to 10 V/cm were considerably longer than the duration of EEG suppression (12s).
19 259 These results indicate that absence of breathing and muscle tone may not be good indicators
20 260 of the duration of unconsciousness. It has been shown that attempts to electrically stun
21 261 broilers with low currents - using either dry electrodes across the head or conventional
22 262 waterbaths – can result in seizures without apparent evidence of epileptiform activity in the
23 263 EEGs (e.g. Raj & O’Callaghan 2004, Raj *et al.* 2006a,b,c).
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43 265 Exposure of the broilers to electric fields of 10, 15, 20 or 25 V/cm resulted in epileptiform
44 266 activity in the EEG for durations that did not differ significantly. This is in agreement with
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46 267 the previously reported data for head-only electrical stunning of broilers (Raj and
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48 268 O’Callaghan, 2004). However, the duration of the EEG suppression following epileptiform
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51 269 activity did not increase with rising field strength. We did not investigate whether the
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53 270 duration of EEG suppression is also dependant on the duration of exposure to the electric
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56 271 field.
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3 273 Previous research (Raj and O'Callaghan, 2004) has shown that head-only electrical stunning
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5 274 of broilers using electrodes placed directly on the head and delivering a 50 Hz or 400 Hz ac
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8 275 current of 100 mA resulted respectively in suppressed EEG levels for 60 or 40 seconds post-
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10 276 stun. Increasing the current to 150 mA did not significantly prolong the duration of EEG
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12 277 suppression. It is not clear why the duration of EEG suppression in this report did not
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15 278 increase with current whereas it did increase with field strength in the waterbath experiment.
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17 279 The difference in the two results may be related to the markedly different duration of
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20 280 suppression of the EEG activity in the two experiments.
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24 282 The use of an electric current through the body to suppress wing flapping would be both
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27 283 illegal and detrimental to bird welfare if the birds were not also rendered immediately
28
29 284 insensible. However because the body current cannot flow unless the birds' head is in
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32 285 contact with the water, the application of the body current and the stunning current are
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34 286 necessarily simultaneous. The approach is very similar in principle to that of the traditional
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36 287 waterbath stunning, since in both a stunning current and an immobilising current are applied
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38 288 simultaneously. The difference is that in the traditional waterbath stunner the same current is
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41 289 used for both purposes whereas in our approach each current is specifically designed to
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43 290 achieve its intended purpose.
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48 292 The results of Experiment 2 pointed to the need for a body current of 25 – 30 mA to suppress
49
50 293 wing flapping in most birds, and accordingly, a current of 32 mA was used in Experiment 4.
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52 294 A current of only 19 mA was used in Experiment 3 and was a mistake made when planning
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54
55 295 the experiment, but had no detrimental effect on the welfare of the birds in the trial because
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57 296 they were all stunned by the head-only stunning current. The fact that no wing flapping was
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60 297 observed during these tests possibly indicates that the one bird in Experiment 2 which did

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3 298 flap with a 2000 Hz current of over 19 mA was exceptional. From a welfare point of view it
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5 299 seems extremely unlikely that the unconsciousness indicated by the EEG measurements in
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8 300 Experiment 3 would be hindered by an increase in body current from 19 mA to 32 mA.
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10 301 Therefore for the purpose of this pilot study we chose not to repeat this trial.
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15 303 The trials reported here focused on the result of a one second exposure to the stunning
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17 304 current. However in practical use the electrical parameters identified in this that was too short
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19 305 due, for example, to the animal struggling away from the waterbath at the last moment. The
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21 306 determination of electrical parameters using a short exposure to the electrical stun is based on
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23 307 the conservative assumption that the period of EEG suppression is not increased by a longer
24
25 308 application of the electrical stun. There is relatively little evidence relevant to broilers in the
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27 309 literature on this relationship, however Gregory & Wotton (1990) and Prinz *et al.* (2010 a,b,c)
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29 310 both suggest a positive correlation between these two factors.
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34 312 An assessment of this approach to poultry stunning with a view to its practical application in
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36 313 the poultry industry raises three significant questions. First, whether practical systems can be
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38 314 designed to deliver the same high standard of welfare at slaughter as was achieved in these
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40 315 preliminary trials; second, if the increased complexity can be justified by the reduced cost of
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42 316 damaged carcasses; and third that the method can be improved to reduce the electrical power
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44 317 requirement without compromising the welfare of the birds.
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51 319 The issue of carcass quality is addressed in a direct carcass quality trial (Lines *et al.* 2011).
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53 320 The question of whether, or how reliably, this approach to electrical stunning can be
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55 321 implemented and remain humane will be only discovered following extensive practical
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57 322 application and development. Before this can take place the power consumption of this
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3 323 approach must be determined as it requires 600 W of electrical power to sustain an electric
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5 324 field of 20 V/cm in one litre of water of conductivity 1.5 mS/cm. A commercial stunning
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7 325 system is likely to require a waterbath containing many litres of water and have a high power
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9 326 requirement. The power requirement of the new method would result in high capital and
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11 327 running costs. Concerns about high power requirements also occurred during the early
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13 328 development of humane fish stunning systems (Lines & Kestin 2003) however further
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15 329 research identified practical and humane solutions which may also be applicable to broilers
16
17 330 (Lines *et al* 2004, 2005, Lambooij *et al* 2008)
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332 **Conclusion and animal welfare implications**

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334 We have described a new alternative to head only electric stunning. Analysis of broiler EEGs
335 indicated that immersion of the head in water of conductivity 2.5 mS/cm supporting a 50 Hz,
336 20 V/cm electric field results in immediate and sustained unconsciousness for 30 seconds.
337 The wing flapping which results from loss of control by the brain can be controlled by
338 simultaneously passing a 2000 Hz, 25 - 30 mA current through the body of the bird. This
339 approach may be suitable for development into a high throughput electrical waterbath
340 stunning system for broilers with the potential to enable high standards of welfare and carcass
341 quality to be achieved simultaneously.

342

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For Peer Review Only

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3 451 **Figure legends**
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8 453 **Figure 1.** Representative EEG signal of a 6 wk broiler chicken following a 1s exposure to an
9
10 454 electrical field in water of 10 V / cm. A. The signal shows epileptiform activity but no
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12 455 subsequent suppression. B. The signal shows epileptiform activity and subsequent
13
14 456 suppression. Exposure to the electric field ceased at time = 0. The data were obtained during
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17 457 Experiment 1.
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22 459 **Figure 2.** Results from Experiment 2 showing the frequency and current passed through the
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24 460 birds and an assessment of whether it suppressed wing flapping in stunned broilers. Solid
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26 461 markers indicate flapping suppressed and open marks indicate flapping not suppressed.
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464 **Table 1.** *Number of broiler chickens in Experiment 1, percentage of stunned birds and mean*
 465 *(±SD) time to cessation of breathing or return of neck tension (behavioural indicators of*
 466 *unconsciousness) after exposure for 1 s to a 50 Hz electric field strength in the water.*

467

Observation	Electric field (V/cm)		
	7.5	8.75	10
Number of birds	13	7	15
% stunned (behavioural assessment)	54%	57%	100%
Time to cessation of breathing, s	20 ± 4	19 ± 3	24 ± 10
Time to return of neck tension, s	42 ± 7	44 ± 4	41 ± 6

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3 469 **Table 2.** *Number of broiler chickens in Experiment 1 and mean (\pm SD) time from the end of*
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6 470 *current exposure to the end of epileptiform EEG activity or suppression after exposure for*
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8 471 *one second to a 50 Hz electric field of various strengths.*

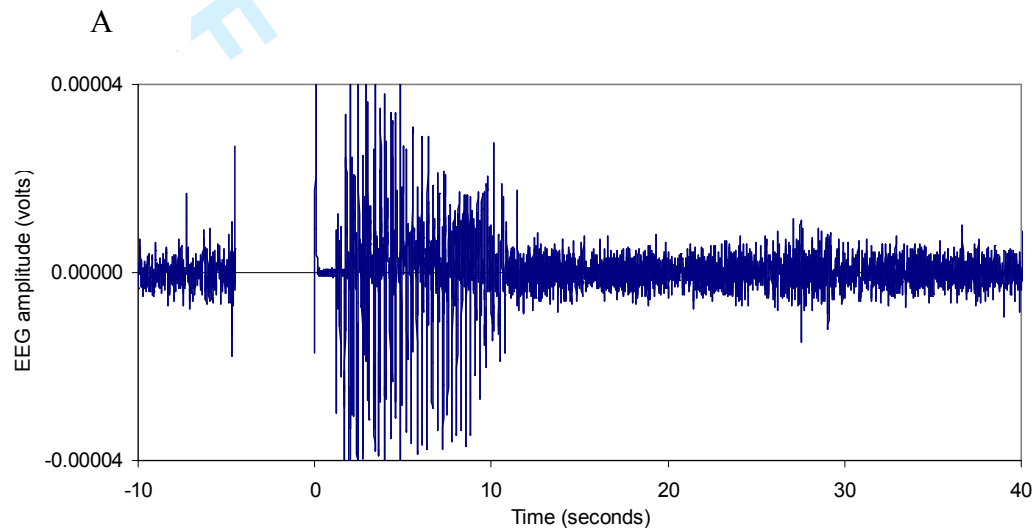
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Observation	Electric field (V/cm)			
	10	15	20	25
Number of birds assessed	6	7	3	1
Time to end of epileptiform EEG activity, s	12 \pm 2	14 \pm 2	13 \pm 2	12
Time to end of EEG suppression, s	12 \pm 2	22 \pm 6	24 \pm 2	28

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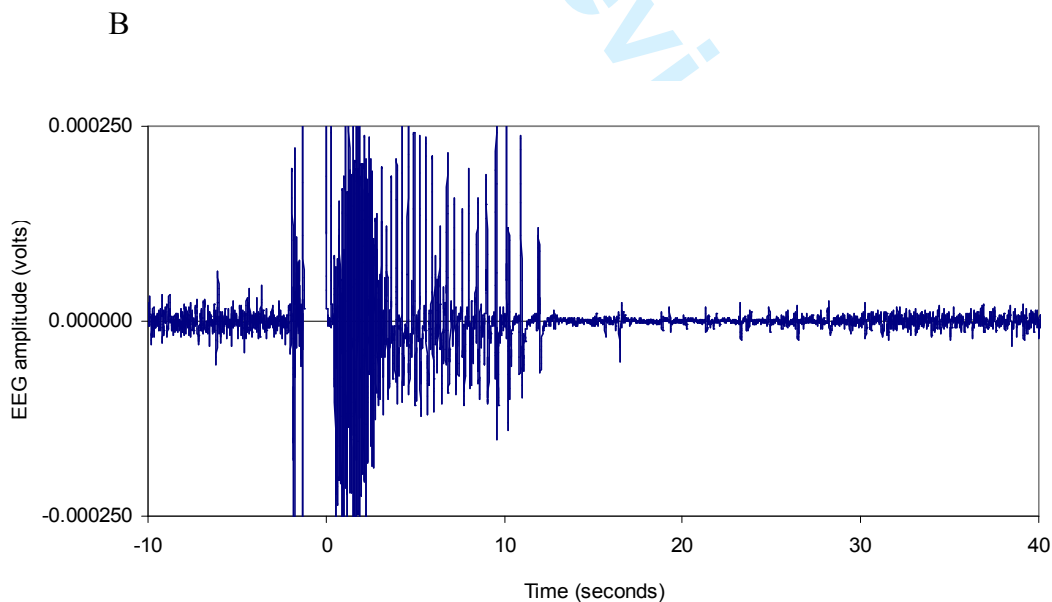
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3 474 **Figure 1.** Representative EEG signal of a 6 wk broiler chicken following a 1s exposure to an
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6 475 electrical field in water of 10 V / cm. A. The signal shows epileptiform activity but no
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10 477 suppression. Exposure to the electric field ceased at time = 0. The data were obtained during
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12 478 Experiment 1.

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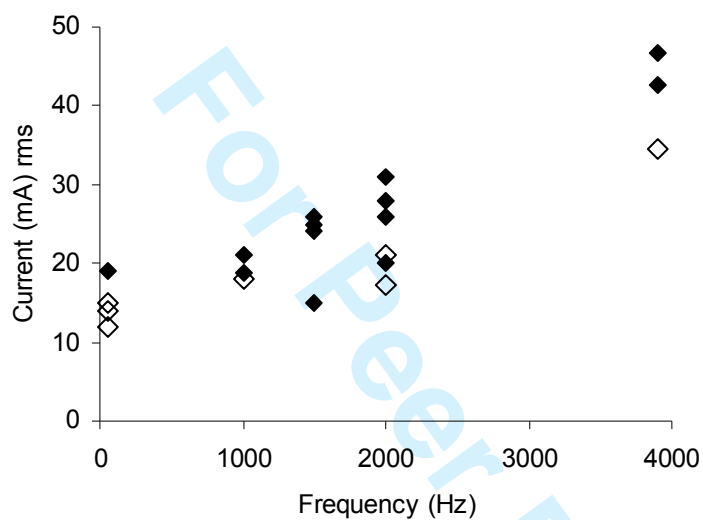
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4 483 **Figure 2.** Plot of electrical current and frequency passed through the body of stunned broiler
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6 484 chickens. Solid markers indicate flapping suppressed and open marks indicate flapping not
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8 485 suppressed.
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