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The evaluation of two commercial electric sheep stunning systems: current applied and the effect on heart function

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8 **the effect on heart function**
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11 4 Running Title: ECG in Sheep
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16 6 Finola Orford¹, Elizabeth A Ford², Steve N Brown¹, Justin McKinstry¹, Philip J Hadley²,
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53 20 **Keywords:** Animal welfare, electrical stunning, electrocardiogram, halal, sheep, voltage
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56 21 current.
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22 Abstract

23 The maintenance of head-only minimum stunning currents for sheep to ≥ 1.0 Amp (EC
24 Regulation 1099/2009) was examined in two trials in a commercial abattoir. In the first trial,
25 a Jetco MS100 stunner failed to maintain the current to >1.0 Amp in 118 of the 228 sheep. In
26 a second trial a Jetco MS105 delivered sufficient current in all sheep ($n = 275$) to meet the
27 legislative requirement, apart from a single animal. Recorded electrocardiograms showed a
28 regular heartbeat, with no evidence of ventricular fibrillation, in all animals in both trials
29 following stunning and neck cut. Only one of the two stun units may therefore be considered
30 to meet the requirements of EC 1099/2009 but both may meet the requirements for halal
31 slaughter where pre-stun is considered acceptable.

33 Introduction

34 There are two types of slaughter of animals for food production from an animal welfare
35 perspective, slaughter with stunning and slaughter without stunning. The derogation from
36 stunning within current legislation (EC 1099/2009) permits religious groups to perform
37 slaughter without stunning where their beliefs dictate. However, the requirements for Halal
38 slaughter can be interpreted to permit the use of a stunning method provided the animals are
39 slaughtered whilst healthy and alive and that the stunning method is recoverable (Fuseini et al
40 2016). Head-only electrical stunning is therefore accepted by many Muslim groups but any
41 change in the applied electrical parameters, for example the requirements of EC Regulation
42 (1099/2009) must be tested to show that there is no change in the animal's ability to recover
43 after the stun.

44 Effective stunning can be produced when sufficient current is passed through the brain. The
45 total impedance of the pathways between the electrodes will depend on the shape, size,

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3 46 material and cleanliness of the electrodes, tissue resistance, the pressure applied during
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5 47 stunning and the voltage used. The time taken to break down the inherent high resistance of
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7 48 living tissue is shorter when higher voltages are applied (Wotton & O'Callaghan, 2002).
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9
10 49 EFSA (2004) reported that when constant voltage stunners are used, the current starts to flow
11
12 50 from zero to the maximum, which would be time dependent on the magnitude of the voltage.
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14 51 However, constant current stunners are designed and constructed in such a way that they
15
16 52 anticipate high resistance in the pathway and hence start with the maximum available voltage.
17
18 53 ~~which in the case of the Jetco MS105 studied in trial 2 was 474 Volts rms.~~ Owing to this, the
19
20 54 target current is reached within the first few current cycles (within milliseconds of the start of
21
22 55 current application) and the applied voltage may also be modulated according to the changes
23
24 56 in the resistance. Therefore, constant current stunners are preferred to constant voltage
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26 57 stunners (EFSA 2004)
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30 58 Stunning an animal prior to slaughter is defined in EC Regulation (1099/2009) as: "any
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32 59 intentionally induced process which causes loss of consciousness and sensibility without
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34 60 pain, including any process resulting in instantaneous death". The duration of this
35
36 61 unconscious state must be long enough to prevent the animal from regaining consciousness
37
38 62 before death occurs by exsanguination.
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41
42 63 EFSA (2004) reported that cardiac ventricular fibrillation threshold testing in experimental
43
44 64 models suggests that cardiac tissue is most sensitive to stimulation between 30 and 60 Hz of
45
46 65 sine wave alternating current and increased stimulus duration increases the effectiveness of
47
48 66 the application (Weirich et al 1983). However, the induction of cardiac ventricular fibrillation
49
50 67 would depend upon the delivery of sufficient electrical current to the myocardium. EC
51
52 68 Regulation 1099/2009 came into operation in January 2013 and specifies the minimum head-
53
54 69 only electrical stunning current as 1.0 Amp for sheep. Previous Codes of Practice (HSA
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56 70 Guidance Notes 1999) had suggested 1.0 Amps for sheep and 0.6 Amps for lambs. Therefore,
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3 71 concern was raised within the Muslim population as to the effect an additional 0.4 Amp at 50
4
5 72 Hz AC could have on the potential for ventricular fibrillation (cardiac arrest) at stunning in
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7 73 lambs. The introduction of WATOK (2015) in England has permitted religious groups
8
9 74 exemption from the minimum electrical parameters required for an effective stun as laid
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11 75 down in EC Regulation (1099/2009), Annex 1. Nevertheless, the application must render the
12
13 76 animals unconscious as assessed by both the Official Veterinarian (OV) and the Animal
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15 77 Welfare Officer (AWO).

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19 78 Previous research has demonstrated that head-only electrical stunning is fully recoverable
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21 79 (Velarde et al 2002; Cook et al 1995, 1996; Velarde et al 2000). However, Gregory and
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23 80 Wotton (1984) found that one sheep of a sample of 61 that received head-only stunning (3 s
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25 81 at 1 Amp, 50 Hz AC) showed ventricular fibrillation. Warriss and Wotton (1981) showed a
26
27 82 similar occurrence with pigs, head-only stunned with 90 volts AC for 15 s. Therefore, there is
28
29 83 a possibility that head-only electrical stunning at low frequency could affect the heart of some
30
31 84 sheep. This trial was undertaken to determine whether the application of 1.0 Amp at 50 Hz
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33 85 AC to lambs and sheep would result in a ventricular fibrillation and hence the death of the
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35 86 animal, contrary to halal requirements.

36 37 38 39 40 41 42 88 **Materials and Methods**

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45 89 Two trials were conducted at a commercial abattoir with a throughput of up to approximately
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47 90 1,500 sheep per day, and a line speed of approximately one sheep per 4.5 seconds. The first
48
49 91 took place on 4th February 2014, the second on 27th January 2015 following the installation of
50
51 92 a new electric stunner. The abattoir used a single v-restrainer to move sheep from the lairage
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53 93 to the point of stunning and sticking, producing sheep acceptable to the halal market, but with
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55 94 all sheep receiving a pre-slaughter electrical stun. Sheep were supplied to the v-restrainer in
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3 95 batches of either 'old season lamb' (OSL) or of adult ewes from the lairage holding pens. No
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5 96 special arrangements were made for the trials regarding the sheep processed or their
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7 97 processing. The line ran as it would on any other normal day to ensure that the measurements
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9
10 98 made were representative of normal commercial practice.

11
12 99 Sheep were individually stunned at the head of the v-restrainer using a Jarvis Model 1J two-
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14 100 pronged handset (JETCO Jarvis Engineering Technologies, Auckland NZ), with a built-in
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17 101 water spray to help reduce contact impedance. The stunning system used in the first trial was
18
19 102 a Jarvis Jetco MS100, manual, head-only electrical stunning system, designed to deliver a
20
21 103 "choke limited" current of at least 1 amp, and set at 1.5A, 50Hz sine wave AC. In the second
22
23 104 trial this was upgraded to a Jarvis Jetco MS105 current limited stunner, again set at 1.5A
24
25 105 (stun current threshold), 50Hz sine wave AC. The Jetco MS105 included a light and alarm
26
27 106 when the required stun duration was reached and a separate miss-stun signal that was initiated
28
29 107 if the stun current threshold was not reached. After stunning, the sheep were rolled out onto a
30
31 108 table where they were stuck and shackled to a conveyor line for further processing.

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35 109 All electrical information was recorded onto an eight channel Vision Data Acquisition
36
37 110 System (Vision XP-LDS Nicolet) with sampling rate set at 20KHz. The RMS current, RMS
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39 111 voltage and stun duration were later extracted from the recordings.

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41
42 112 Stunning voltage was measured using a differential alternating current (AC) voltage probe
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44 113 (Elditest GE8115) across the electrical output from the stunner control unit to the stunning
45
46 114 electrodes. The voltage probe measured AC voltage across the electrodes and produced a
47
48 115 matching, low voltage waveform onto the Vision DAS. Stunning current was measured using
49
50 116 an AC current clamp (Fluke i30s) around the positive electrical output from the electrical
51
52
53 117 | stunning electrodes and was connected directly to the vision DAS.

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3 118 Post-stun electrocardiogram profiles were recorded for the sheep sampled using a system
4
5 119 specially designed to transfer electrocardiogram data onto the Vision DAS. Following
6
7 120 stunning, shackling and neck cut, individual animals had fine needle electrodes in a bipolar
8
9 121 apex lead array inserted sub-dermally. The needles were attached to leads of a sufficient
10
11 122 length to allow time for the ECG to be recorded successfully as the animals travelled along
12
13 123 the overhead rail during bleeding. The ECG signal was amplified using a Gould Bio-amp, set
14
15 124 to filter out waveforms above 40 Hz (High pass) and below 2 Hz (Low pass). The signal was
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17 125 then passed through a Humbug 40/60Hz filter to eliminate background noise from the mains
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19 126 supply. The presence of ventricular fibrillation was assessed at the time of recording and
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21 127 verified retrospectively by examination of the ECG profile for a rhythmic QRS complex.
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26 128 Due to the time constraints of recording individual animal details at stunning, and ECG as a
27
28 129 sheep moved on the conveyor line, data were collected for approximately every 5th old
29
30 130 season lamb (OSL) and approximately every 4th adult ewe. In the first trial only the electrical
31
32 131 parameters of the stun were recorded and whether an animal was an OSL or ewe. In the
33
34 132 second trial further details were recorded at the time of the stun: wool cover (on a scale of 1
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36 133 to 5 (Figure 1)), the presence of horns, whether the animal was properly wetted prior to the
37
38 134 stun, and electrode placement: in which position 1 was where the electrodes were placed in
39
40 135 front of the ears; position 2, where the electrodes were placed in line with the ears and
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42 136 position 3, where the electrodes were placed behind the ears and towards the neck. This
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44 137 scoring system and the normal electrode placement positions were identified during a prior
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46 138 visit to the abattoir.
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54 140 Figure 1 Here
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3 142 To facilitate the further measurements taken and to match individual sheep to the electrical
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5 143 stun data, in the second trial the sheep to be sampled were marked across the shoulders with a
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7 144 coloured spray in the lairage section of the v-restrainer before stunning and were also
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9 145 identified on the Vision Data Acquisition System (Vision DAS) immediately after stun with a
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11 146 pulse marker triggered by the researcher recording the physical details of the sheep and the
12
13 147 stunning process.

14 148 For both trials the cold carcass weights of all the animals within a batch were available.
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17 149 These were not matched to individual sheep but were used to calculate a mean weight for the
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19 150 batches from the lairage pens.

20
21 151 The study was approved by the University of Bristol's internal ethical review process.
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28 29 153 *Statistical Analysis*

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32 154 The percentage of sheep showing a 'normal' ECG following stunning and sticking is reported
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34 155 together with a 95% confidence interval for the estimate, calculated using Wilson's method
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36 156 (Altman et. al., 2000). Summary statistics are reported for the stun parameters. Additionally,
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38 157 general linear models were used to assess the effect of the sheep specific variables recorded
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40 158 in trial two on the RMS current achieved. The residuals from the model were assessed for
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42 159 normality and homogeneity of variance.

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46 160 The ability of the two stunners to maintain a stun current above a threshold despite
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48 161 differences in resistance between individual sheep is of importance. The relationships
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50 162 between current, voltage and impedance for the individual stuns from both trials are
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52 163 presented as a series of graphs. The results of a bench test of the Jetco MS105 used in trial 2
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54 164 are also presented.

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3 166 **Results**
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6 167 In trial one electrical stun parameters and ECG were recorded for 228 sheep (144 OSL, 79
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8 168 ewes and 5 rams). The mean duration of current application was 3.9s (± 0.544 sd). All 228
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10 169 sheep showed continued heart function following stunning and sticking and no animals
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12 170 displayed ventricular fibrillation in their ECG. An example of an electrocardiogram recorded
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14 171 within the trial is shown in Figure 2 and summary statistics for the trial are shown in Table 1.
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20 173 Figure 2 Here
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26 175 Table 1 Here
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32 177 It can be seen from Table 1 that the minimum RMS current recorded was 0.42A. One
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34 178 hundred and eighteen of the 228 sheep (52%) received an RMS current that was less than
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36 179 1.00 A. The distribution of RMS current recorded is shown in Figure 3.
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42 181 Figure 3 Here
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48 183 In trial two electrical stun parameters and ECG were recorded for 275 sheep (225 OSL, 50
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50 184 ewes). In trial two, the mean duration of current application was 3.42 seconds (\pm ~~sd~~ = 0.062
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52 185 ~~sd~~) for OSL and 3.44 seconds (± 0.023 sd) for adult sheep, respectively. All 275 sheep
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54 186 showed continued heart function following stunning and sticking and no animals displayed
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56 187 ventricular fibrillation in their ECG. Summary statistics for the trial are shown in Table 2.
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3 188 One animal received a RMS current of less than 1A. The distribution of RMS currents seen in
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5 189 trial two is shown in Figure 4.
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11 191 Table 2 Here
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22 195 Across both trials 100 per cent of animals showed continued heart function as demonstrated
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24 196 by ECG. A 95% confidence interval for all animals in the trial is 99.2 to 100%, for OSL
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26 197 alone 99.0 to 100%, for ewes 97.1 to 100% and for the 5 rams the 95% confidence interval is
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28 198 56.6 to 100%.
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31
32 199 Using data from trial 2, a general linear model was used to test for an effect of stun order,
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34 200 electrode placement, carcass weight, the presence of horns, and degree of wool cover on the
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36 201 RMS current achieved. All predictive variables bar 'the presence of horns' and 'electrode
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38 202 placement' were treated as continuous variables. There was a highly significant relationship
39
40 203 between the order in which the sheep were stunned and the RMS current ($p < 0.001$), with a
41
42 204 mean decrease in current of 2.05×10^{-4} (se 0.433×10^{-4}) A per sheep recorded throughout the
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44 205 study (note that approximately every fifth animal on the line was recorded). There was a
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46 206 trend for an effect of wool cover which failed to reach statistical significance ($p = 0.083$), in
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48 207 which each unit increase in wool cover score was associated with a 5.87×10^{-3} (se 3.376×10^{-3})
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50 208 ³) A decrease in RMS current ie only approximately 6mA decrease in current for every unit
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53 209 increase in wool cover.
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3 210 The output of the Jetco MS105 was bench tested to measure the effect of increasing
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5 211 impedance on voltage and current output using the stunner's 1.5 Amp setting. The bench test
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7 212 results of the Jetco MS105 are shown in Figure 5.
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13 214 Figure 5 Here
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18
19 216 Figure 6 shows a plot of the sheep impedances, (calculated from the RMS voltage and RMS
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21 217 current using Ohm's law) against the applied RMS voltage recorded from the two different
22
23 218 stunners in trials one (Jetco MS100) and two (Jetco MS105). The results from the Jetco
24
25 219 MS105 bench test are also superimposed as a solid line. For further clarification of the
26
27 220 performance of the two stunners, Figure 7 shows the relationship between impedance
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29 221 (calculated) and the measured RMS voltage for each animal in the two trials. The results from
30
31 222 the Jetco MS105 bench test are superimposed as a solid line and the theoretical relationship
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33 223 that would be seen with a constant voltage source of 320 V is given as a dashed line.
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40 225 Figure 6 Here
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45
46 227 Figure 6. The relationship between sheep impedance, (calculated from the RMS voltage and
47
48 228 RMS current using Ohm's law) and the applied RMS voltage from the two different stunners
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50 229 in trials one (Jetco MS100) and two (Jetco MS105). The results from the Jetco MS105 bench
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52 230 test are superimposed as a solid line.
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3 232 Figure 7 Here
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9 234 Figure 7. The measured RMS current output of the two stunners tested in trials one (Jetco
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11 235 MS100)1 and two (Jetco MS105)2 plotted against the impedance (calculated) of the
12
13 236 individual sheep. The MS105 bench test results are shown as a solid line and the theoretical
14
15 237 relationship ($V = I \times R$) for the current given a constant voltage of 320 V is shown as a
16
17 238 dashed line.
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22 23 240 **Discussion**

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26 241 **Heart Activity:** The halal requirement for the stunning method to be recoverable and
27
28 242 therefore for animals to be alive at the time of slaughter was met with every stunning
29
30 243 application in both trials (n = 503). The recorded ECG demonstrated continued heart function
31
32 244 following stunning and sticking and no animals displayed ventricular fibrillation in their
33
34 245 ECG. The amount of current delivered will depend upon the voltage and total impedance in
35
36 246 the pathway (between the electrodes). It is possible that with very long application times at
37
38 247 low frequency (50 Hz) the current field developed by a head-only application could have
39
40 248 spread sufficiently to affect cardiac tissue and induce ventricular fibrillation, but in practice
41
42 249 thi~~ese~~ was shown not to occur. The average stun application time was <3.5s during both
43
44 250 trials which was insufficient to result in a ventricular fibrillation in any of the animals
45
46 251 recorded. Further insurance against the induction of ventricular fibrillation would be to
47
48 252 increase the frequency of the stunning current but this~~which~~ would significantly increase the
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50 253 threshold current required for fibrillation (Weirich et al 1983).
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3 255 **Trial 1. Jetco MS100:** The requirement of a minimum current of 1.0 Amp for all classes of
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5 256 sheep (EC 1099/2009) was not achieved during trial one using the Jetco MS100 stunner. The
6
7 257 voltage range produced of 213 to 404 V (Figure 6 and Table 1); did not maintain the current
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9
10 258 above the chosen setting of 1.5 A. It can be seen from Figure 7 that in reality the output
11
12 259 current produced by the Jetco MS100 was little better than would have been achieved by a
13
14 260 constant voltage of 320 V and therefore this stunner showed little if any current control.
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18 262 **Trial 2. Jetco MS105:** The Jetco MS 105 delivered sufficient current to meet the legislative
19
20 263 requirement of 1.0 A (EC 1099/2009) for all except one of the 275 animals in trial two, for
21
22 264 which the current was 0.97 A. The limiting factor with all electrical stunning equipment that
23
24 265 employs some form of current control is the maximum voltage that the output can reach when
25
26 266 applied across the impedance of the animal's head. The maximum voltage produced by the
27
28 267 Jetco MS105 when tested in the laboratory was 474 V RMS and the maximum impedance
29
30 268 above which the stunner will not deliver 1.0 Amp was 380 Ω (Figure 5). Figure 7
31
32 269 demonstrates how the current changes in response to changes in impedance. However, the
33
34 270 use of a current limiting choke to control the output voltage dependant on the impedance of
35
36 271 the animal's head within the design of this stunner resulted in better current control, but
37
38 272 current was not limited to the legislative requirement of 1.0 Amp. Table 2 Shows the range of
39
40 273 currents produced from 0.97 to 1.38 Amps. It is possible that the higher currents could affect
41
42 274 both heart function if applied for an extended application time and/or produce deleterious
43
44 275 meat quality (Gregory 1998).
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50
51 277 The statistical analysis showed an effect of order on the current applied to each animal. The
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53 278 current applied decreased slowly but steadily. This effect was most likely due to a gradual
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55 279 build-up of dirt on the electrode tips, perhaps combined with operator fatigue. There was also
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3 280 an effect of decreased stun current in the sheep with the greater wool cover. The decrease in
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5 281 current of approximately 6mA for every unit increase in wool cover would have been
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7 282 inconsequential in terms of stun efficacy.
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11 284 Electrode design can have a large effect on the magnitude of the current flow by changing the
12
13 285 electrode/skin contact impedance (Sparrey & Wotton 1997). The design of the pin electrodes
14
15 286 on the stunner handset, used in both trials, results in a very small area of contact with the
16
17 287 animal's head, but is required to ensure that the wool is penetrated and contact is made with
18
19 288 the skin. It is recommended that the design of the electrodes should be modified to increase
20
21 289 this area of contact, possibly by increasing the number of pins, which would help maintain
22
23 290 the impedance to current flow below 380 Ω when using the 1.5 A setting, thus maintaining a
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25 291 current level of ≥ 1.0 A. It is also important to ensure that the water jets are directed onto the
26
27 292 tips of the electrodes to minimise contact impedance.
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33 34 294 **Animal Welfare Implications and Conclusions**

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36 295 EC (1099/2009) regulates the minimum current for effective head-only electrical stunning for
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38 296 sheep at 1.0 A. The operation of stunning equipment with some form of current **limitation**
39
40 297 **regulation** has welfare advantages by ensuring the applied current is greater than 1.0 A.
41
42 298 However, the equipment is limited by the maximum voltage that can safely be manually
43
44 299 applied in an abattoir, as determined by the Health and Safety Executive within the UK.
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50 301 The study was approved by the University of Bristol's internal ethical review process.
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52 302

53 54 303 **Acknowledgements**

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4
5 305 the study. The work was funded by AHDB Beef & Lamb.
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3 356 Table 1. Summary statistics for the stun parameters and sheep weights from trial one (n =
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	Min	Max	Mean	SD
Stun duration (s)	2.52	9.96	3.90	0.54
RMS current (A)	0.42	2.85	1.07	0.43
RMS voltage (V)	213	404	334	44
Cold carcass wt (kg)	9.50	36.50	19.38	3.96

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3 364 Table 2. Summary statistics for the stun parameters and sheep weights from trial two (n =
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	Min	Max	Mean	SD
Stun duration (s)	3.04	3.46	3.42	0.06
RMS current (A)	0.97	1.38	1.25	0.06
RMS voltage (V)	117	415	270	45
Cold carcass wt (kg)	17.33	23.20	19.51	2.39

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Wool score 1 (0 % wool)



Wool score 2 (25 % wool)



Wool score 3 (50 % wool)



Wool score 4 (75 % wool)

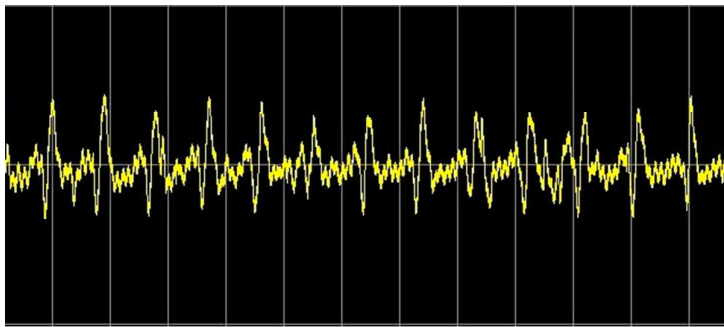


Wool score 5 (100 % wool)

Figure 1. Wool cover scoring system.

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390 Figure 2. Normal electrocardiogram recorded from a sheep post-slaughter (Divisions are at

391 200 millisecond intervals).

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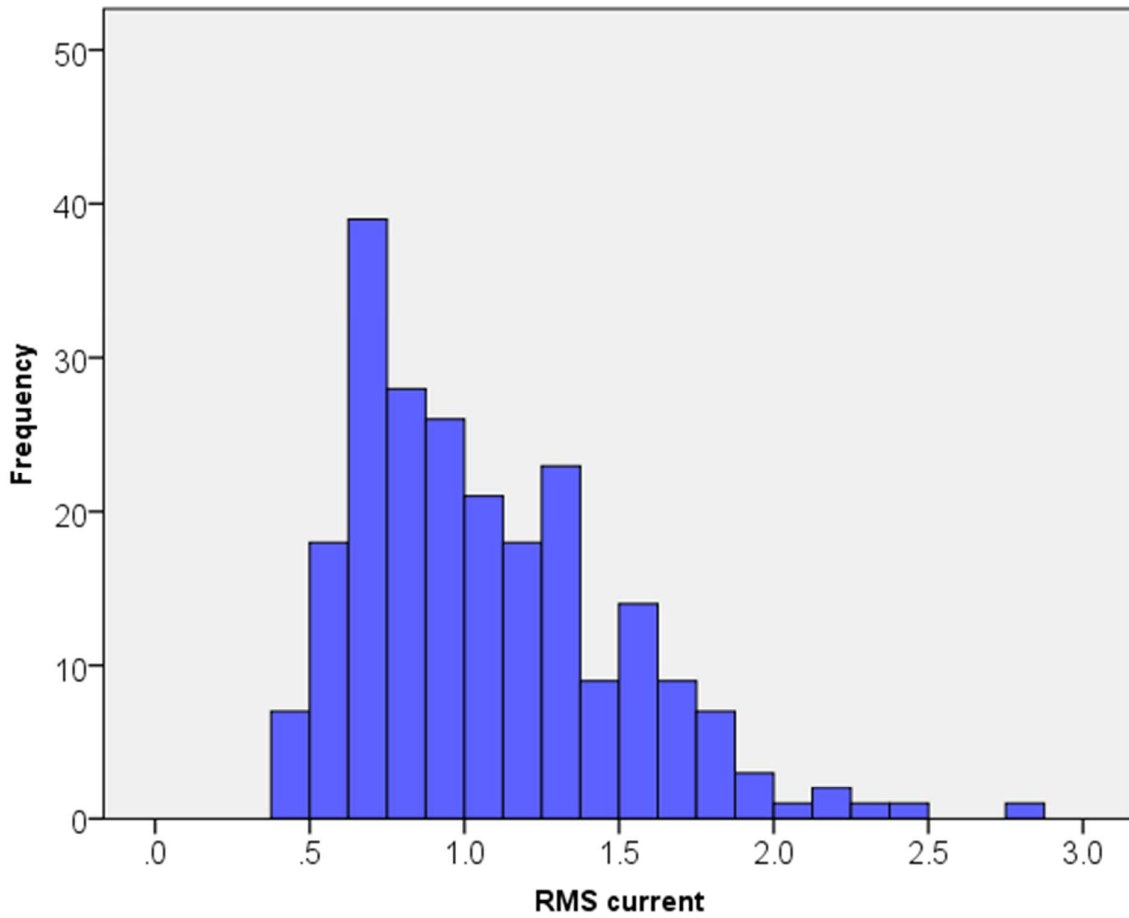
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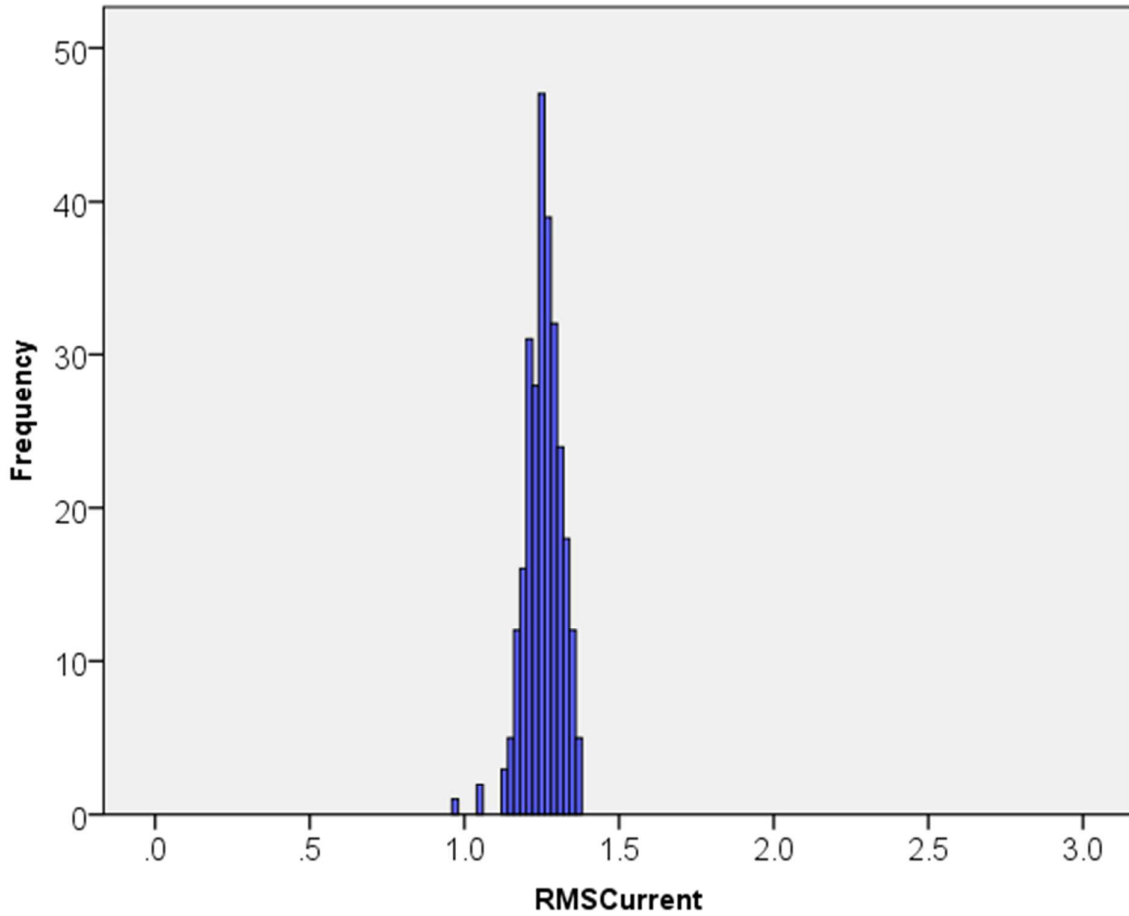
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Figure 3. Histogram showing the distribution of the RMS stunning currents received by individual sheep within trial one.

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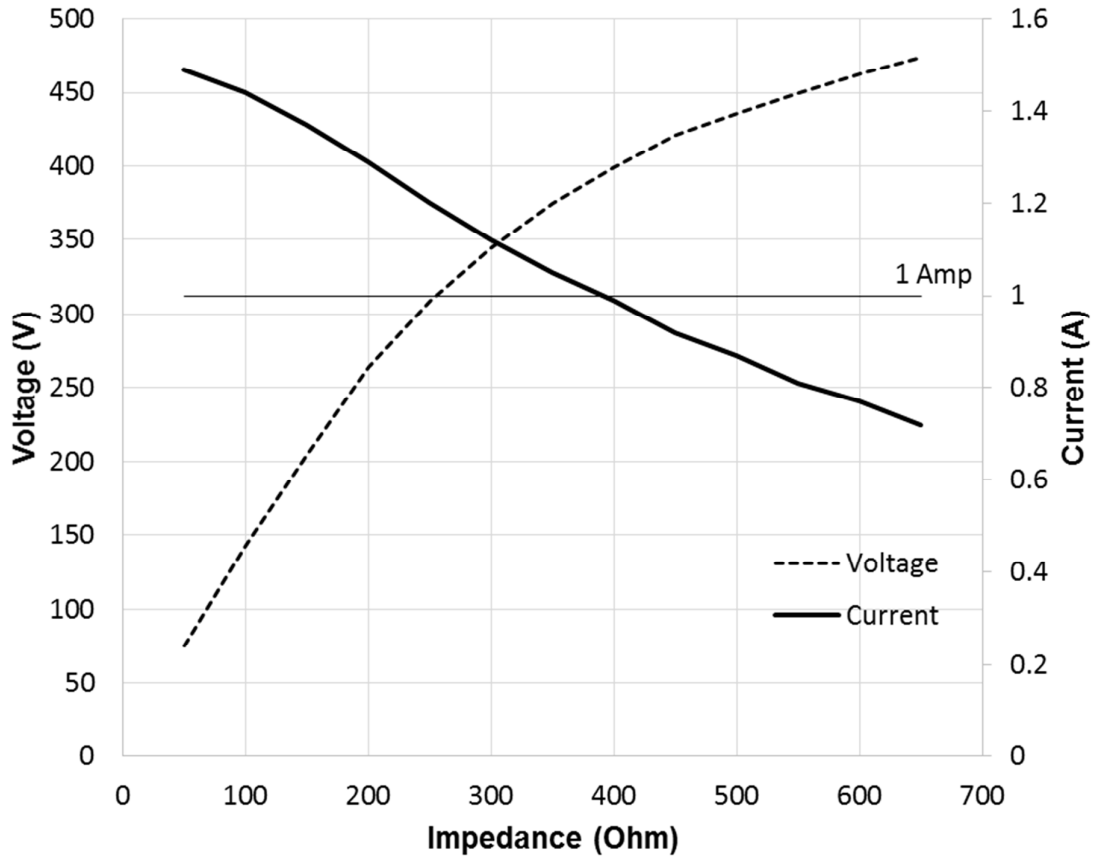


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421 Figure 4. Histogram showing the distribution of the RMS stunning currents received by
422 individual sheep within trial two.

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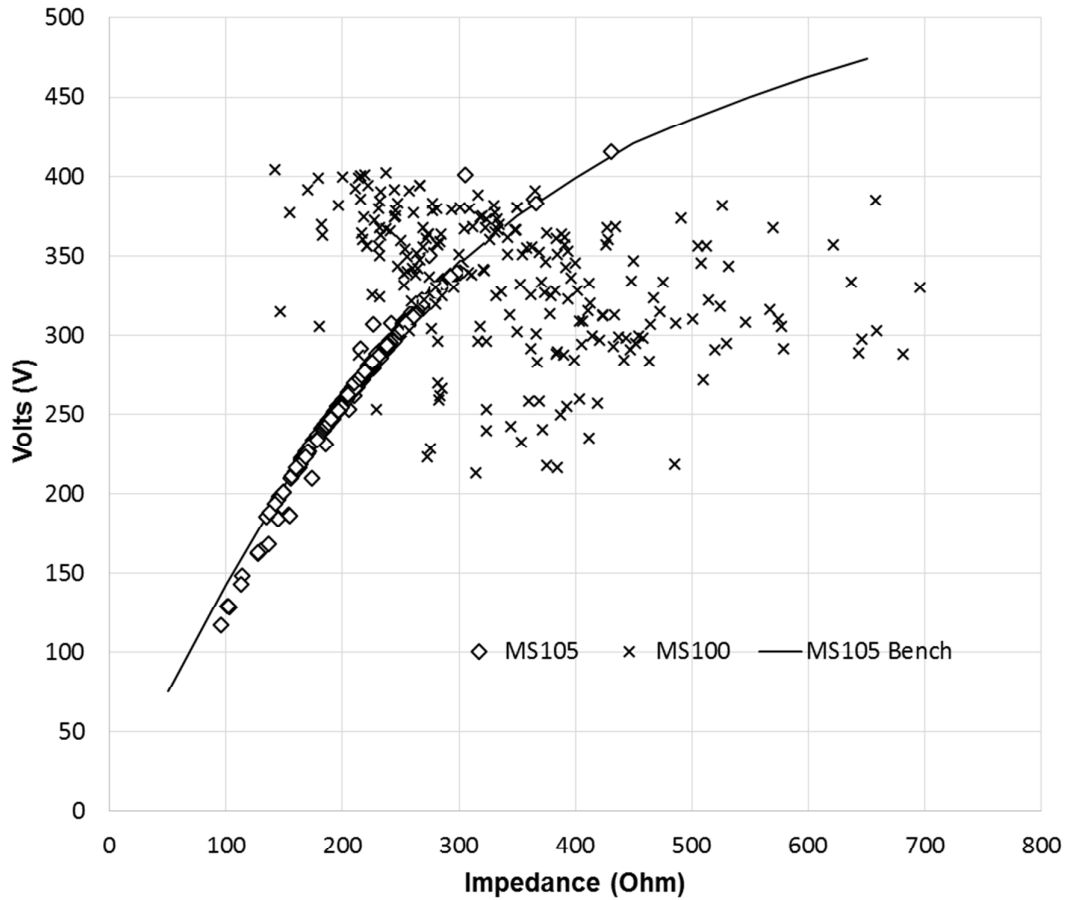
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Figure 5. The Jetco MS105 bench test results: the effect of increasing impedance on voltage and the current output (with the machine set at its 1.5 Amp setting).

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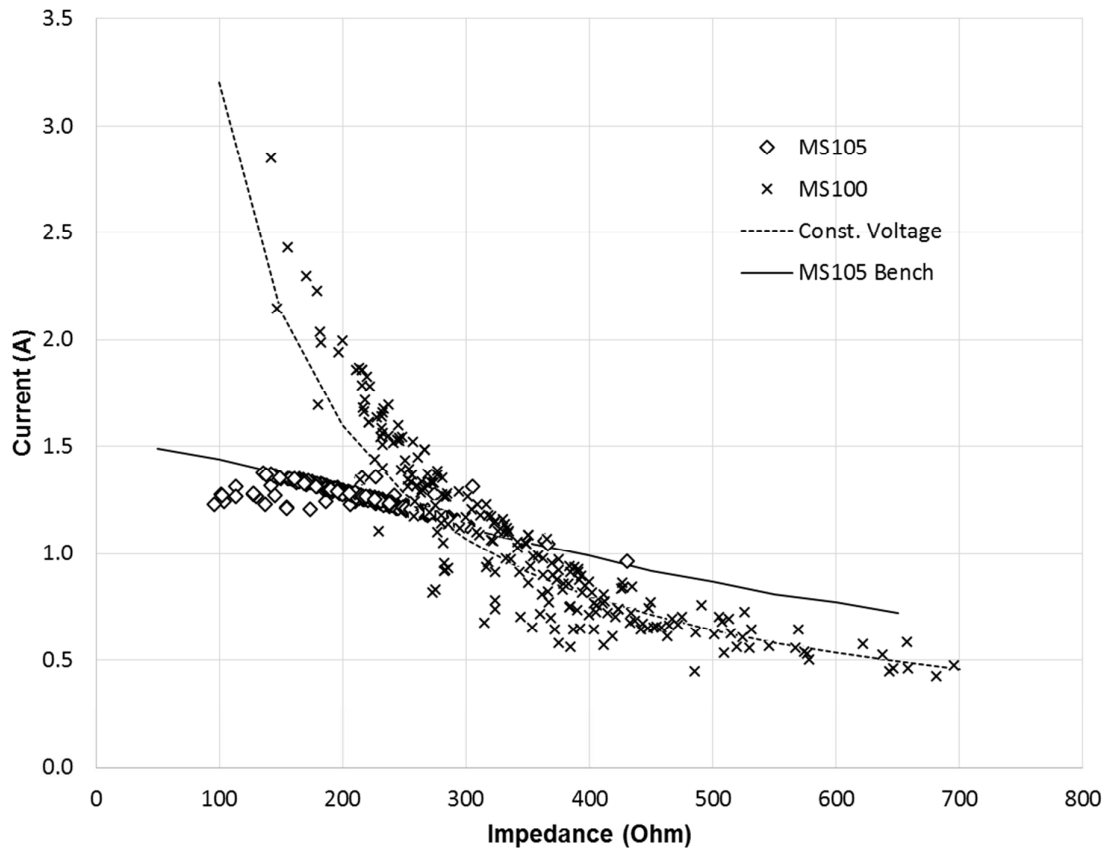
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440 Figure 6. The relationship between sheep impedance, (calculated from the RMS voltage and
441 RMS current using Ohm's law) and the applied RMS voltage from the two different stunners
442 in trials one (Jetco MS100) and two (Jetco MS105). The results from the Jetco MS105 bench
443 test are superimposed as a solid line.

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451 Figure 7. The measured RMS current output of the two stunners tested in trials one (Jetco

452 MS100)1 and two (Jetco MS105)2 plotted against the impedance (calculated) of the

453 individual sheep. The MS105 bench test results are shown as a solid line and the theoretical

454 relationship ($V = I \times R$) for the current given a constant voltage of 320 V is shown as a

455 dashed line.

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