



**Student Final Report No. 7793**

**March 2014**

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electrode positions and their impact on the effectiveness of the  
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## 1. Abstract

Traditional sheep slaughter usually involves the animals being initially stunned using head-only electrical stunning and then slaughtered by exsanguination. Current welfare legislation requires the electrodes to be applied in a position that spans the brain. In terms of animal welfare, an optimum position of between the eye and the base of the ear on each side of the head is recommended. In manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen, deviations from this position are, however, likely to occur. This study aimed to assess whether variations in electrode positions can have an impact on the effectiveness of the stun in this method of sheep stunning, as well as whether the amount of wool present in the application sites of the electrodes can have an impact. Three abattoirs, named as Abattoirs A, B, and C were visited. For each sheep, the electrode position and the amount of wool was assessed using scoring systems of seven and five scores, respectively. The signs of an effective stun were also assessed and various electrical parameters were measured. The impact of electrode position and the amount of wool on the effectiveness of the stun was assessed only in Abattoir C, as all of the sheep were stunned effectively in Abattoirs A and B, but their impact on the electrical parameters was assessed in each abattoir. The study found that, in Abattoir C, the electrode position had a significant impact ( $P < 0.05$ ) on the effectiveness of the stun, with it being least effective when the electrodes were applied in a position that was not spanning the brain, but the amount of wool did not have any significant impact ( $P > 0.05$ ). In Abattoir A, the electrode position was found to have a significant impact ( $P < 0.01$ ) on the root mean square (RMS) voltage and the impedance, with them being the lowest when the electrodes were applied in the optimum position, but the amount of wool did not have any significant impact ( $P > 0.05$ ) on any of the electrical parameters in any of the abattoirs. Overall, the study highlights the importance of electrode position for assuring effective stunning.

**Keywords** – *head-only electrical stunning, sheep, electrode positions, wool*

## 2. Introduction

On January 1<sup>st</sup> 2013, Council Regulation (EC) No 1099/2009 relating to the 'protection of animals at the time of killing' came into effect in the European Union. This Regulation, with the exception of religious methods of slaughter, makes it a requirement for animals to be stunned before they are slaughtered. The objective of stunning prior to slaughter is to render the animal immediately unconscious and insensible, for a duration which is sufficient to ensure that there is no recovery of consciousness and sensibility before death intervenes (Zivotofsky and Strous, 2012). This is considered to be humane, by sparing the animal any avoidable pain, distress or suffering during the interval between when it is stunned and when it is slaughtered, provided that pre-slaughter stunning is carried out correctly and the animal is slaughtered as quickly as possible following pre-slaughter stunning.

In the United Kingdom, sheep are traditionally slaughtered by a two-stage process that commonly involves them being initially stunned using head-only electrical stunning and then slaughtered by exsanguination. In head-only electrical stunning, two electrodes are applied on the head of the animal and a current is passed through the brain to induce a general epileptiform insult (Lambooy, 1982). During the general epileptiform insult, the brain enters a seizure-like state which is synonymous with a loss of consciousness and sensibility and, in sheep, lasts for around 30 seconds (s) (Velarde *et al.*, 2002). In this time, the animal must be slaughtered by exsanguination, which, in sheep, involves severing the major blood vessels in the neck and causing death by stopping the flow of blood to the brain (EFSA, 2004).

In order for head-only electrical stunning of sheep to be effective, specific electrical criteria must be met. The production of a stunned state requires the passing of a sufficient amount of current through the brain of the animal for a certain period of time. To achieve this, an adequate amount of voltage needs to be applied to overcome the initial resistance of the head of the animal. In Council Regulation (EC) No 1099/2009, it is specified that a minimum current of 1.00 amp (A) is needed in head-only electrical stunning of sheep, and that this needs to be delivered by applying the electrodes in a position that spans the brain. The time required to apply this minimum current is not stipulated in the Regulation, however, in a study by Cook *et al.* (1995), it was found that it needs to be applied for a minimum time of 200 milliseconds (ms), in order to be able to induce a general epileptiform insult.

With these electrical criteria set out either in the legislation or in industry guidance, one could easily make the assumption that head-only electrical stunning of sheep is always carried out effectively in practice. It has, nevertheless, been found that the effectiveness of head-only electrical stunning of sheep can be affected by a variety of factors, such as the position of the electrodes and the presence of wool, as found in a study by Velarde *et al.* (2000). These have the potential to

compromise the welfare of the animal by affecting how much current is passed through the animal's brain and consequently, the ability to achieve an effective stun. Despite the fact that factors such as the presence of wool are important in terms of their effect, the most important factor that can affect the effectiveness of head-only electrical stunning of sheep is, however, the position of the electrodes.

It has been found, in the study by Velarde *et al.* (2000), that the effectiveness of head-only electrical stunning of sheep can be affected if the electrodes are not in a position that spans the brain. Similar findings were also found in a study by Anil and McKinstry (1998), where the effect of electrode position on the effectiveness of head-only electrical stunning of pigs was assessed. In general, if the electrodes are in a position that spans the brain, then the current is able to flow from one to the other, along a direct pathway through the brain, thus enabling the production of an effective stun (Sparrey and Wotton, 1997). If, however, the electrodes are not in a position that spans the brain, the current can flow through other parts of the body and bypass the brain, therefore leading to the production of an ineffective stun and the infliction of unnecessary pain, distress or suffering (Grandin, 2013).

In both the study by Velarde *et al.* (2000) on sheep and the study by Anil and McKinstry (1998) on pigs, an optimum electrode position is recommended to be between the eye and the base of the ear on each side of the head. With this position, the brain not only lies in the most direct pathway between the two electrodes, but there are also wet routes, namely the optic and auditory nerves, which serve as ideal pathways of low resistance for the current to flow through the skull and to the brain (Sparrey and Wotton, 1997). It has been described elsewhere, such as by Croft and Hume (1956), that one of the worst electrode positions is across the neck, particularly the lower neck, as with this position, the animal can look as if it were unconscious and insensible, due to the current affecting the spinal cord and causing paralysis, but still be conscious and sensible, due to the current bypassing the brain.

While the study by Velarde *et al.* (2000) is important with regards to its assessment of the effect of electrode position on the effectiveness of head-only electrical stunning of sheep, only two different electrode positions were assessed, in comparison to five in the study by Anil and McKinstry (1998) on pigs. In abattoirs where the electrodes are applied manually or automatically on individual sheep in a restrainer-conveyor, it is likely that only one or two different electrode positions will be observed as the animals are always presented in a fixed position. However, in abattoirs where the electrodes are applied manually on individual sheep free-standing within a group in a stunning pen, the animals are never presented in a fixed position, so other electrode positions are likely to be observed. This was found with pigs in a survey by Anil and McKinstry (1993) of pig abattoirs in England and Wales.

With the study by Velarde *et al.* (2000) being the only relevant one concerning the area of interest, the aim of this study was to thus fill a current gap in the research and assess variations in electrode positions and their impact on the effectiveness of the stun, in manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen. The amount of wool present in the sites of application of the electrodes was also taken into account. Overall, it was hoped that this study would provide more thorough evidence of the effect of electrode position on the effectiveness of head-only electrical stunning of sheep than that provided formerly, so that the industry can be better informed about where the electrodes should be positioned to prevent animal welfare being compromised.

### **3. Materials and methods**

#### **3.1. Abattoirs**

Three small to medium-sized abattoirs which carry out manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen were visited over a period of three days. These abattoirs, for reasons of confidentiality, were given the names Abattoir A, Abattoir B, and Abattoir C, in accordance with the order in which they were visited.

#### **3.2. Animals**

A total of 330 sheep were stunned and slaughtered during the visits to the abattoirs, with 87 during the visit to Abattoir A, 42 during the visit to Abattoir B, and 201 during the visit to Abattoir C. All 330 sheep were polled and also of varying breeds, ages and sizes.

#### **3.3. Stunning and slaughter**

In each abattoir, the sheep were brought into the stunning pen, where two operators were present, in groups of between around 10 and 20. The sheep were individually stunned by means of manual head-only electrical stunning and then shackled, hoisted and stuck.

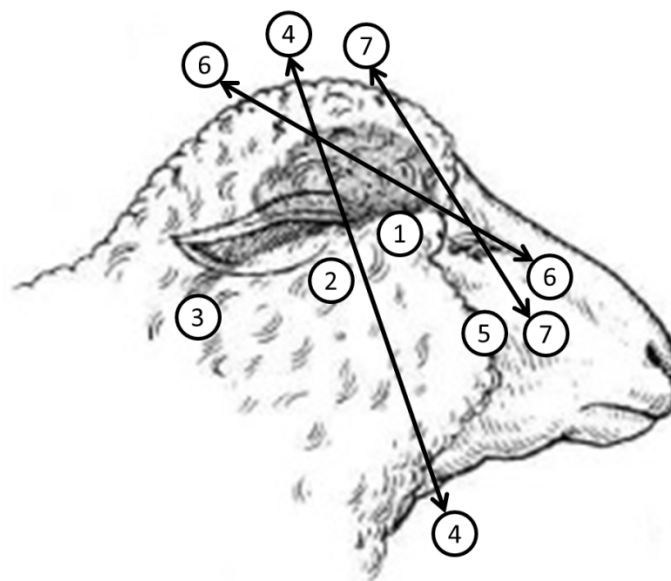
#### **3.4. Equipment**

In each of the abattoirs, the sheep were stunned using a pair of hand-held, scissor-type dry stunning tongs. These delivered a sine wave alternating current (AC) at a frequency of 400 hertz (Hz) in Abattoir A and of 50 Hz in Abattoirs B and C. The type and make of stunner and the electrode design also differed in each abattoir. In Abattoir A, a constant current stunner (FREUND) set at 1.00 A was used and the electrode design was a rectangular array of sharp metal teeth with a metal spike in the centre. In Abattoir B, a constant voltage stunner (Stork) set at 255 volts (V) was used and the electrode design was a rectangular array of sharp metal teeth. In Abattoir C, a constant voltage stunner (Nijhuis) set at 260-270 V was used and the electrode design was a

circular plate with an outer ring of blunt metal teeth surrounding a metal point in the centre. The stun durations also differed in each abattoir. In Abattoir A, an audible alarm sounded when a stun duration of three s had been achieved by the operator. In Abattoirs B and C, however, there were no audible or visual alarms, so the stun durations that were achieved were solely at the discretion of the operator.

### 3.5. Electrode positions

During stunning, the electrode positions on each sheep were assessed and recorded using the scoring system shown in Figure 1, where: position 1 was between the eye and the base of the ear on each side of the head; position 2 was below the base of the ear on each side of the head; position 3 was across the neck, behind the ears; position 4 was placement of one electrode on top of the head and the other under the head; position 5 was on the nose/jaw; position 6 was placement of one electrode behind the ear and the other on the nose; and position 7 was placement of one electrode between the eye and the base of the ear and the other on the nose. Positions 1-5 were taken from the study by Anil and McKinstry (1998) on pigs. These were identified in the survey by Anil and McKinstry (1993). Positions 6 and 7 were identified in a trial run of the study which took place earlier in Abattoir B.



**Figure 1.** The scoring system that was used to assess and record the electrode positions. Position 1: between the eye and the base of the ear on each side of the head; Position 2: below the base of the ear on each side of the head; Position 3: across the neck, behind the ears; Position 4: placement of one electrode on top of the head and the other under the head; Position 5: on the nose/jaw; Position 6: placement of one electrode behind the ear and the other on the nose; Position 7: placement of one electrode between the eye and the base of the ear and the other on the nose.

### 3.6. Wool

Unlike in the study by Velarde *et al.* (2000) where the wool in the application sites of the electrodes was assessed and recorded as merely present or absent, this study took into account variations in wool on sheep and used a scoring system to assess and record the amount of wool present in these sites. This was also deemed necessary because, in comparison to the study by Velarde *et al.* (2000) which was conducted in Spain, this study was carried out in the United Kingdom where sheep are likely to have a greater amount of wool present in these sites due to the more moderate climate. The scoring system that was used is shown in Figure 2. The wool scores in this were 0, 1, 2, 3, and 4. These corresponded to the following percentages of wool: 0 %, 25 %, 50 %, 75 %, and 100 %, respectively.



Wool score 0  
(0 % wool)



Wool score 1  
(25 % wool)



Wool score 2  
(50 % wool)



Wool score 3  
(75 % wool)



Wool score 4  
(100 % wool)

**Figure 2.** The scoring system that was used to assess and record the amount of wool present in the sites of application of the electrodes. Wool score 0: 0 % wool; Wool score 1: 25 % wool; Wool score 2: 50 % wool; Wool score 3: 75 % wool; Wool score 4: 100 % wool. The photographs were used as an approximate guide only.

### **3.7. Signs of an effective stun**

The signs of an effective head-only electrical stun, as described by EFSA (2004) and Grandin (2010), were assessed and recorded for each sheep just after stunning, immediately before and during hoisting, and immediately before and during bleeding. The signs that were assessed and recorded just after stunning were the presence of a tonic seizure, immediate collapse, the absence of righting reflex, the absence of vocalisations, and the absence of rhythmic breathing. The signs that were assessed and recorded immediately before and during hoisting were the presence of a tonic-clonic seizure, the absence of righting reflex, the absence of vocalisations, and the absence of rhythmic breathing. The signs that were assessed and recorded immediately before and during bleeding were the absence of righting reflex, the absence of vocalisations, and the absence of rhythmic breathing.

### **3.8. Electrical parameters**

The current and voltage profiles of each stun were measured using root mean square (RMS) current and voltage probes, and recorded onto a Nicolet "Vision" Data Acquisition System for later analysis. A PR 30 (LEM HEME Ltd) current probe was clamped around the live output within the stunner control panel and measurements were made with a resolution of 1.00 milliamp. A differential voltage probe (MX 9003, Metrix) was used to record the voltage across the isolated output from the stunner control panel. The recording system was calibrated using a factory calibrated Fluke 123 Industrial ScopeMeter.

### **3.9. Statistical analysis**

All of the data that was collected was initially presented in Microsoft Excel 2010 and then analysed using the statistical package SPSS (version 19, IBM SPSS Inc). Differences between means were tested using univariate analysis of variance (ANOVA), and post hoc multiple comparisons were made using Tukey HSD test where this was deemed appropriate. Both univariate ANOVA and Tukey HSD test were set at a significance level of  $P < 0.05$ .

## **4. Results**

### **4.1. Electrode positions**

#### **4.1.1. Electrode position frequencies**

The electrode position frequencies and their percentages in each abattoir and in total are shown in Table 1. There was variation in the electrode positions that were observed in each abattoir, with only positions 1, 2, 4, 5, and 6 being observed in Abattoir A, and only positions 1, 5, 6, and 7 being observed in Abattoir B. Abattoir C was the only abattoir of the three in which all seven electrode positions were observed. The most frequent electrode position that was observed in each abattoir

and in total was, nevertheless, position 1. The most infrequent electrode positions that were observed in total were positions 3 and 4. As these two electrode positions were so infrequent, they were consequently excluded from the data set. Therefore, the following results only include electrode positions 1, 2, 5, 6, and 7, and a total of 320 animals instead of 330, with 86 in Abattoir A, 42 in Abattoir B, and 192 in Abattoir C. Table 2 shows the electrode position frequencies and their percentages in each abattoir and in total following the exclusion of positions 3 and 4 from the data set.

**Table 1.** Electrode position frequencies (n) and percentages (%).

Electrode position	Abattoir						Total	
	A		B		C			
	n	%	n	%	n	%	n	%
1	67	77.01	36	85.71	107	53.23	210	63.64
2	3	3.45	0	0.00	21	10.45	24	7.27
3	0	0.00	0	0.00	4	1.99	4	1.21
4	1	1.15	0	0.00	5	2.49	6	1.81
5	6	6.90	4	9.53	26	12.94	36	10.91
6	10	11.49	1	2.38	20	9.95	31	9.39
7	0	0.00	1	2.38	18	8.95	19	5.76
Total	87	100.00	42	100.00	201	100.00	330	100.00

**Table 2.** Electrode position frequencies (n) and percentages (%) excluding positions 3 and 4.

Electrode position	Abattoir						Total	
	A		B		C			
	n	%	n	%	n	%	n	%
1	67	77.91	36	85.71	107	55.73	210	65.63
2	3	3.49	0	0.00	21	10.94	24	7.50
5	6	6.97	4	9.53	26	13.54	36	11.25
6	10	11.63	1	2.38	20	10.42	31	9.69
7	0	0.00	1	2.38	18	9.37	19	5.93
Total	86	100.00	42	100.00	192	100.00	320	100.00

#### 4.1.2. Electrode positions and their impact on the effectiveness of the stun

The number and percentage of animals that were stunned in each abattoir is shown in Table 3. In Abattoirs A and B, all of the animals were stunned effectively. However, in Abattoir C, only 169 of the 192 animals (88.02 %) were stunned effectively. The impact of electrode position on the effectiveness of the stun could therefore only be assessed in Abattoir C, as the electrode positions did not have any impact on the effectiveness of the stun in Abattoirs A and B. The impact of electrode position on the number and percentage of animals that were stunned in Abattoir C is shown in Table 4, and a comparison of the mean number of animals that were stunned in Abattoir C to show the impact of electrode position is shown in Table 5. The electrode position was found to have a significant impact on the effectiveness of the stun ( $P < 0.05$ ). The percentages and means show that the effectiveness of the stun was most effective when the electrodes were applied in position 6, and that the effectiveness of the stun decreased when the electrodes were applied in positions 7, 2, 1, and 5 in order of decreasing effectiveness. The effectiveness of the stun was, nevertheless, only found to be significantly different between the means of electrode positions 1 and 5.

**Table 3.** The number (n) and percentage (%) of animals that were stunned in each abattoir.

	Abattoir		
	A	B	C
n stunned	86	42	169
n not stunned	0	0	23
% stunned	100.00	100.00	88.02
% not stunned	0.00	0.00	11.98

**Table 4.** The impact of electrode position on the number (n) and percentage (%) of animals that were stunned in Abattoir C.

	Electrode position				
	1	2	5	6	7
n stunned	96	19	18	19	17
n not stunned	11	2	8	1	1
% stunned	89.72	90.48	69.23	95.00	94.44
% not stunned	10.28	9.52	30.77	5.00	5.56

**Table 5.** Comparison of the mean number of animals that were stunned in Abattoir C to show the impact of electrode position.

	Electrode position					VR	P-value	Sig.
	1	2	5	6	7			
Mean ±	0.90 <sup>b</sup>	0.90 <sup>ab</sup>	0.69 <sup>a</sup>	0.95 <sup>ab</sup>	0.94 <sup>ab</sup>	2.77	0.029	*
SD	± 0.31	± 0.30	± 0.47	± 0.22	± 0.24			

VR variance ratio

\*P<0.05

Means with the same superscript do not differ significantly.

#### 4.1.3. Electrode positions and their impact on the electrical parameters

From the current and voltage profiles, the peak current at 200 ms, the mean RMS current, and the mean RMS voltage measurements were obtained for each stun. From the mean RMS current and the mean RMS voltage measurements, the mean impedance for each stun was calculated using Ohm's Law: Impedance (R) = Voltage (V) / Current (I). The impact of electrode position on the peak current at 200 ms, the mean RMS current, the mean RMS voltage, and the mean impedance was assessed in Abattoir A, Abattoir B, and Abattoir C, as shown in Tables 6, 7, and 8, respectively. In Abattoirs B and C, the electrode position had no significant impact on the peak current at 200 ms, the mean RMS current, the mean RMS voltage, or the mean impedance (all P>0.05). In Abattoir A, the electrode position did not have a significant impact on the peak current at 200 ms or the mean RMS current (both P>0.05), but it did, however, have a significant impact on the mean RMS voltage and the mean impedance (both P<0.01). The means show that the mean RMS voltage and the mean impedance were lowest with position 1 and increased with positions 2, 5, and 6 in increasing order. The means between positions 1 and 6 for the mean RMS voltage and the mean impedance were, however, the only means which were found to be significantly different.

**Table 6.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, and mean impedance in Abattoir A to show the impact of electrode position.

	Electrode position				VR	P-value	Sig.
	1	2	5	6			
	Mean $\pm$ SD						
Peak current at 200 ms (A)	1.06 $\pm$ 0.05	1.01 $\pm$ 0.01	1.02 $\pm$ 0.02	1.05 $\pm$ 0.07	1.38	0.256	NS
Mean RMS current (A)	1.02 <sup>a</sup> $\pm$ 0.01	1.02 <sup>ab</sup> $\pm$ 0.00	1.02 <sup>ab</sup> $\pm$ 0.00	1.02 <sup>b</sup> $\pm$ 0.00	2.61	0.057	NS
Mean RMS voltage (V)	134.12 <sup>a</sup> $\pm$ 19.25	152.68 <sup>ab</sup> $\pm$ 22.53	153.30 <sup>ab</sup> $\pm$ 36.58	162.79 <sup>b</sup> $\pm$ 29.04	6.21	0.001	**
Mean impedance ( $\Omega$ )	131.09 <sup>a</sup> $\pm$ 19.14	149.05 <sup>ab</sup> $\pm$ 21.92	150.19 <sup>ab</sup> $\pm$ 36.50	159.85 <sup>b</sup> $\pm$ 29.18	6.24	0.001	**

A amps, V volts,  $\Omega$  ohms

VR variance ratio

NS not significant, \*\*P<0.01

Means in a row with the same superscript do not differ significantly.

**Table 7.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, and mean impedance in Abattoir B to show the impact of electrode position.

	Electrode position				VR	P-value	Sig.
	1	5	6	7			
	Mean $\pm$ SD						
Peak current at 200 ms (A)	2.46 $\pm$ 0.46	2.49 $\pm$ 0.78	2.79 $\pm$ 0.00	3.29 $\pm$ 0.00	1.04	0.386	NS
Mean RMS current (A)	2.12 $\pm$ 0.27	2.23 $\pm$ 0.34	2.17 $\pm$ 0.00	2.30 $\pm$ 0.00	0.31	0.817	NS
Mean RMS voltage (V)	255.90 $\pm$ 1.13	255.03 $\pm$ 1.51	256.30 $\pm$ 0.00	255.75 $\pm$ 0.00	0.73	0.541	NS
Mean impedance ( $\Omega$ )	122.60 $\pm$ 15.76	116.71 $\pm$ 19.63	118.09 $\pm$ 0.00	110.99 $\pm$ 0.00	0.33	0.804	NS

A amps, V volts,  $\Omega$  ohms

VR variance ratio

NS not significant

**Table 8.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, and mean impedance in Abattoir C to show the impact of electrode position.

	Electrode position					VR	P-value	Sig.
	1	2	5	6	7			
	Mean $\pm$ SD							
Peak current at 200 ms (A)	1.27 $\pm$ 0.40	1.26 $\pm$ 0.40	1.31 $\pm$ 0.53	1.27 $\pm$ 0.34	1.13 $\pm$ 0.42	0.56	0.693	NS
Mean RMS current (A)	1.46 $\pm$ 0.50	1.46 $\pm$ 0.52	1.36 $\pm$ 0.59	1.54 $\pm$ 0.43	1.21 $\pm$ 0.51	1.25	0.290	NS
Mean RMS voltage (V)	274.44 $\pm$ 9.91	274.75 $\pm$ 2.79	276.12 $\pm$ 2.97	274.10 $\pm$ 2.85	276.55 $\pm$ 2.32	0.52	0.719	NS
Mean impedance ( $\Omega$ )	223.95 $\pm$ 135.29	213.79 $\pm$ 82.65	293.39 $\pm$ 326.38	196.83 $\pm$ 76.76	278.05 $\pm$ 141.02	1.56	0.186	NS

A amps, V volts,  $\Omega$  ohms

VR variance ratio

NS not significant

## 4.2. Wool

### 4.2.1. Wool score frequencies

The wool score frequencies and their percentages in each abattoir and in total are shown in Table 9. As with the electrode positions, there was variation in the wool scores that were recorded in each abattoir. In Abattoirs A and C, all five wool scores were recorded, whereas in Abattoir B, only wool scores 0 and 2 were recorded. The most frequent wool score in each abattoir and in total was wool score 0, followed by wool scores 1, 2, 3, and 4 in order of decreasing frequency in Abattoirs A and C and in total.

**Table 9.** Wool score frequencies (n) and percentages (%).

Wool score	Abattoir						Total	
	A		B		C		n	%
	n	%	n	%	n	%		
0	68	79.07	41	97.62	173	90.10	282	88.13
1	10	11.62	0	0.00	9	4.68	19	5.94
2	4	4.65	1	2.38	4	2.10	9	2.81
3	2	2.33	0	0.00	3	1.56	5	1.56
4	2	2.33	0	0.00	3	1.56	5	1.56
Total	86	100.00	42	100.00	192	100.00	320	100.00

### 4.2.2. Wool scores and their impact on the effectiveness of the stun

The impact of wool score on the effectiveness of the stun could only be assessed in Abattoir C for reasons which have already been mentioned. There was no significant impact of wool score on the effectiveness of the stun ( $P>0.05$ ), as shown in Table 10.

**Table 10.** Comparison of the mean number of animals that were stunned in Abattoir C to show the impact of wool score.

	Wool score					VR	P-value	Sig.
	0	1	2	3	4			
Mean ±	0.88	0.89	1.00	0.67	1.00	0.56	0.694	NS
SD	± 0.33	± 0.33	± 0.00	± 0.58	± 0.00			

VR variance ratio

NS not significant

### 4.2.3. Wool scores and their impact on the electrical parameters

The impact of wool score on the peak current at 200 ms, the mean RMS current, the mean RMS voltage, and the mean impedance is shown in Tables 11, 12, and 13, for Abattoir A, Abattoir B, and Abattoir C, respectively. The wool score did not have a significant impact on any of these electrical parameters in any of the abattoirs (all  $P > 0.05$ ).

**Table 11.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, and mean impedance in Abattoir A to show the impact of wool score.

	Wool score					VR	P-value	Sig.
	0	1	2	3	4			
	Mean $\pm$ SD							
Peak current at 200 ms (A)	1.05 $\pm$ 0.05	1.06 $\pm$ 0.05	1.03 $\pm$ 0.02	1.04 $\pm$ 0.05	1.11 $\pm$ 0.13	1.04	0.392	NS
Mean RMS current (A)	1.02 $\pm$ 0.01	1.03 $\pm$ 0.00	1.02 $\pm$ 0.00	1.02 $\pm$ 0.01	1.03 $\pm$ 0.00	2.28	0.068	NS
Mean RMS voltage (V)	137.63 $\pm$ 23.00	140.48 $\pm$ 22.98	155.12 $\pm$ 20.53	175.25 $\pm$ 57.20	128.82 $\pm$ 3.99	1.81	0.134	NS
Mean impedance ( $\Omega$ )	134.67 $\pm$ 22.97	137.05 $\pm$ 22.72	151.81 $\pm$ 20.28	172.17 $\pm$ 57.15	125.01 $\pm$ 4.18	1.81	0.135	NS

A amps, V volts,  $\Omega$  ohms

VR variance ratio

NS not significant

**Table 12.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, and mean impedance in Abattoir B to show the impact of wool score.

	Wool score		VR	P-value	Sig.
	0	2			
	Mean $\pm$ SD				
Peak current at 200 ms (A)	2.49 $\pm$ 0.50	2.39 $\pm$ 0.00	0.04	0.835	NS
Mean RMS current (A)	2.13 $\pm$ 0.27	2.29 $\pm$ 0.00	0.31	0.583	NS
Mean RMS voltage (V)	255.81 $\pm$ 1.17	256.27 $\pm$ 0.00	0.15	0.702	NS
Mean impedance ( $\Omega$ )	121.89 $\pm$ 15.82	112.14 $\pm$ 0.00	0.37	0.546	NS

A amps, V volts,  $\Omega$  ohms

VR variance ratio

NS not significant

**Table 13.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, and mean impedance in Abattoir C to show the impact of wool score.

	Wool score					VR	P-value	Sig.
	0	1	2	3	4			
	Mean $\pm$ SD							
Peak current at 200 ms (A)	1.25 $\pm$ 0.41	1.43 $\pm$ 0.52	1.44 $\pm$ 0.58	0.94 $\pm$ 0.25	1.35 $\pm$ 0.59	1.07	0.373	NS
Mean RMS current (A)	1.43 $\pm$ 0.51	1.67 $\pm$ 0.42	1.56 $\pm$ 0.70	0.99 $\pm$ 0.50	1.12 $\pm$ 0.50	1.40	0.237	NS
Mean RMS voltage (V)	274.72 $\pm$ 7.74	274.05 $\pm$ 3.18	280.56 $\pm$ 14.02	276.00 $\pm$ 2.65	276.67 $\pm$ 1.15	0.65	0.628	NS
Mean impedance ( $\Omega$ )	235.35 $\pm$ 172.13	175.62 $\pm$ 51.00	203.09 $\pm$ 72.96	355.15 $\pm$ 240.61	282.82 $\pm$ 120.70	0.76	0.552	NS

A amps, V volts,  $\Omega$  ohms

VR variance ratio

NS not significant

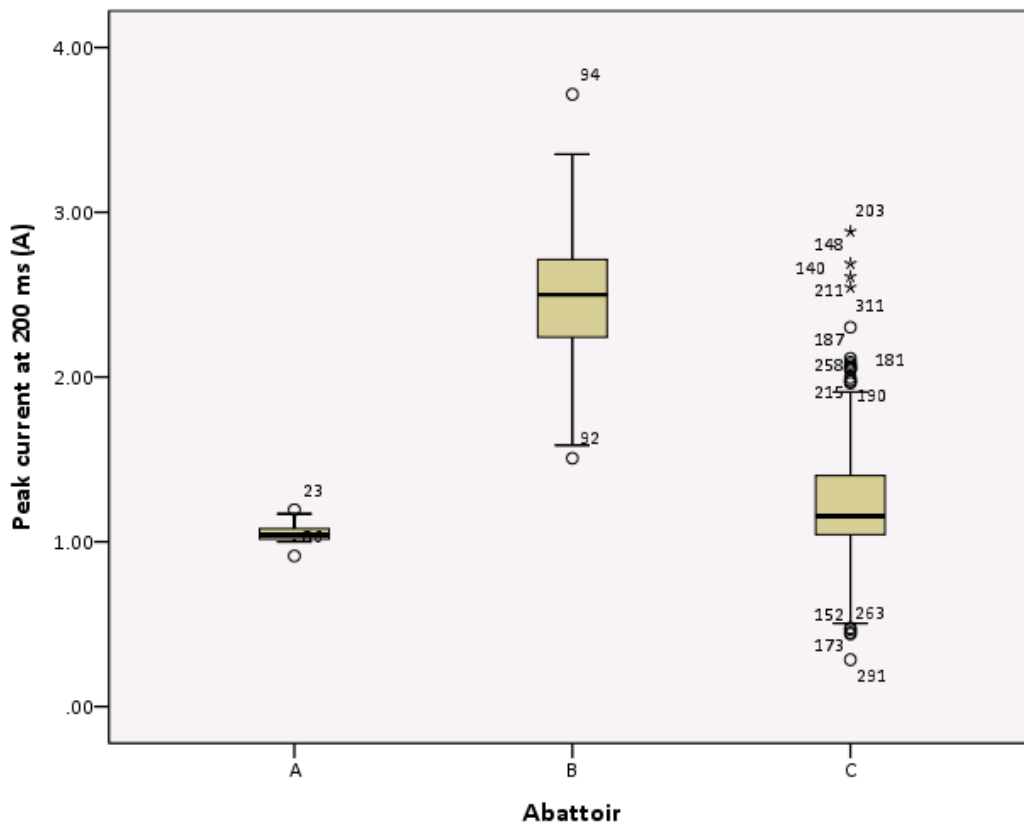
### 4.3. Electrical parameters

#### 4.3.1. Electrical parameters and their impact on the effectiveness of the stun

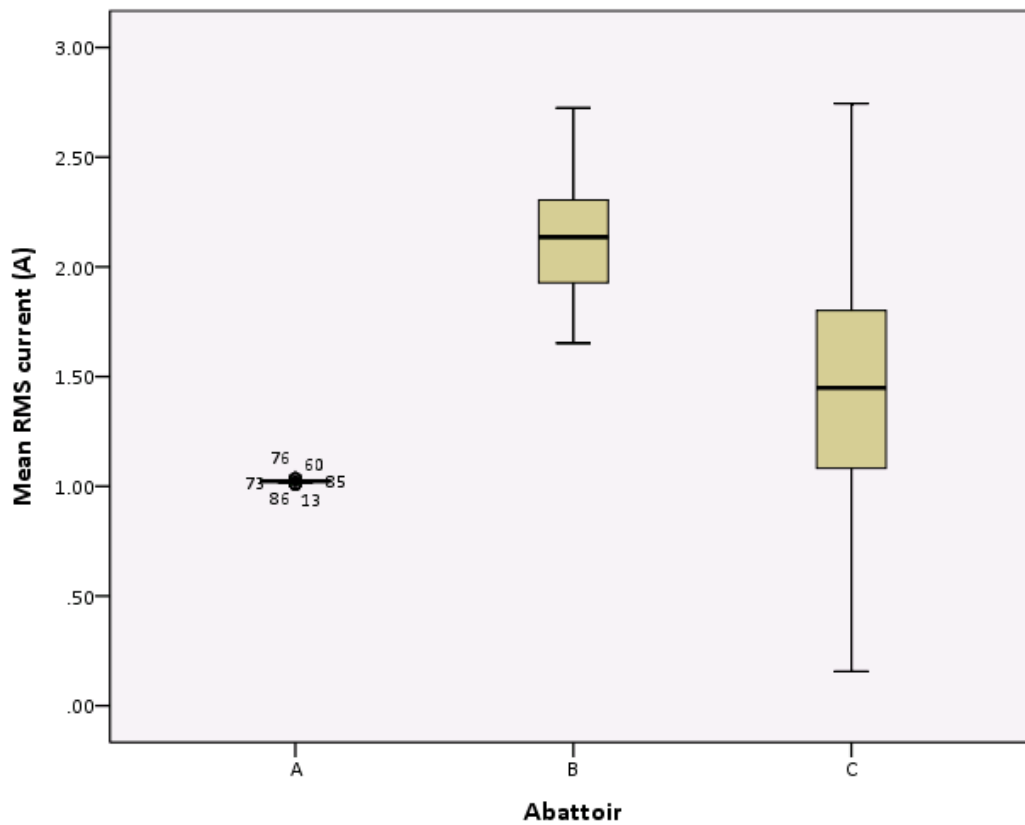
The impact of the peak current at 200 ms, the mean RMS current, the mean RMS voltage, the mean impedance, and the stun duration on the effectiveness of the stun in Abattoir C was assessed. There was no significant impact of any of these electrical parameters on the effectiveness of the stun (all  $P > 0.05$ ).

#### 4.3.2. Differences in the electrical parameters between abattoirs

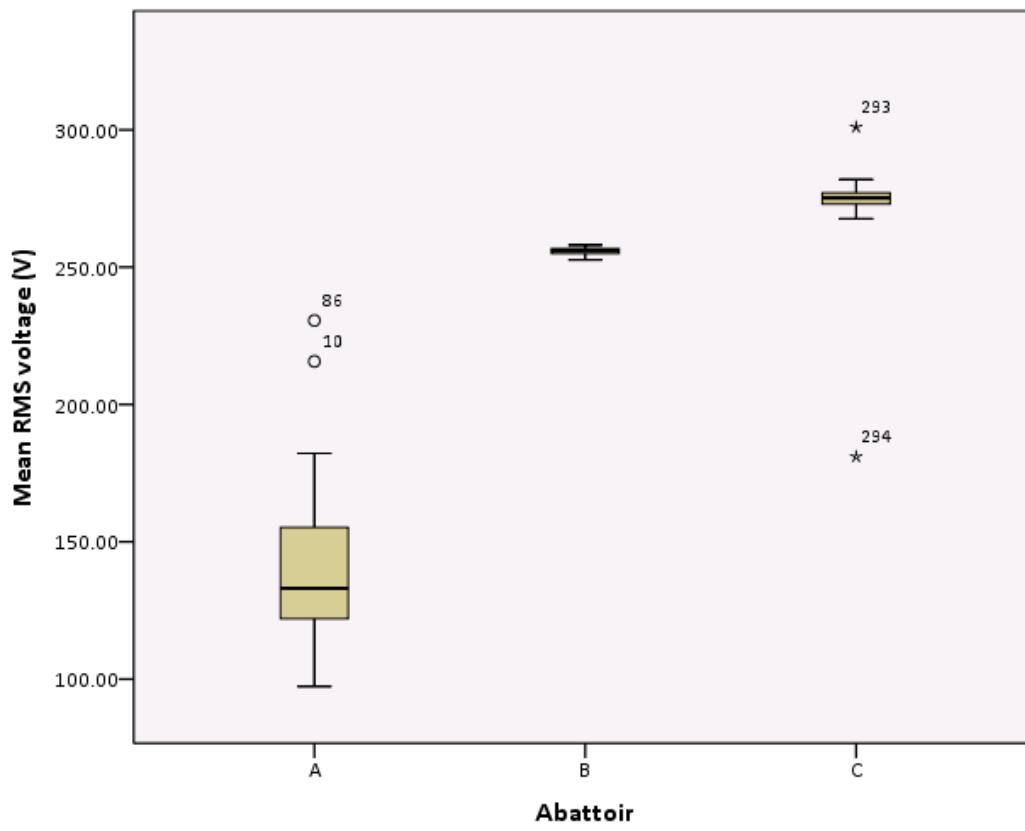
The differences in the electrical parameters between abattoirs were assessed to try and determine why the effectiveness of stunning was significantly worse in Abattoir C in contrast to Abattoirs A and B. Figures 3, 4, 5, 6, and 7 show the differences in the peak current at 200 ms, the mean RMS current, the mean RMS voltage, the mean impedance, and the stun durations between abattoirs, respectively. In Table 14, the means of each of these electrical parameters between abattoirs were found to be significantly different (all  $P < 0.001$ ). In contrast to Abattoirs A and B, Abattoir C showed lower and larger variations in the peak current at 200 ms and in the mean RMS current, higher mean RMS voltages, and higher and larger variations in the stun durations and most notably, in the mean impedance.



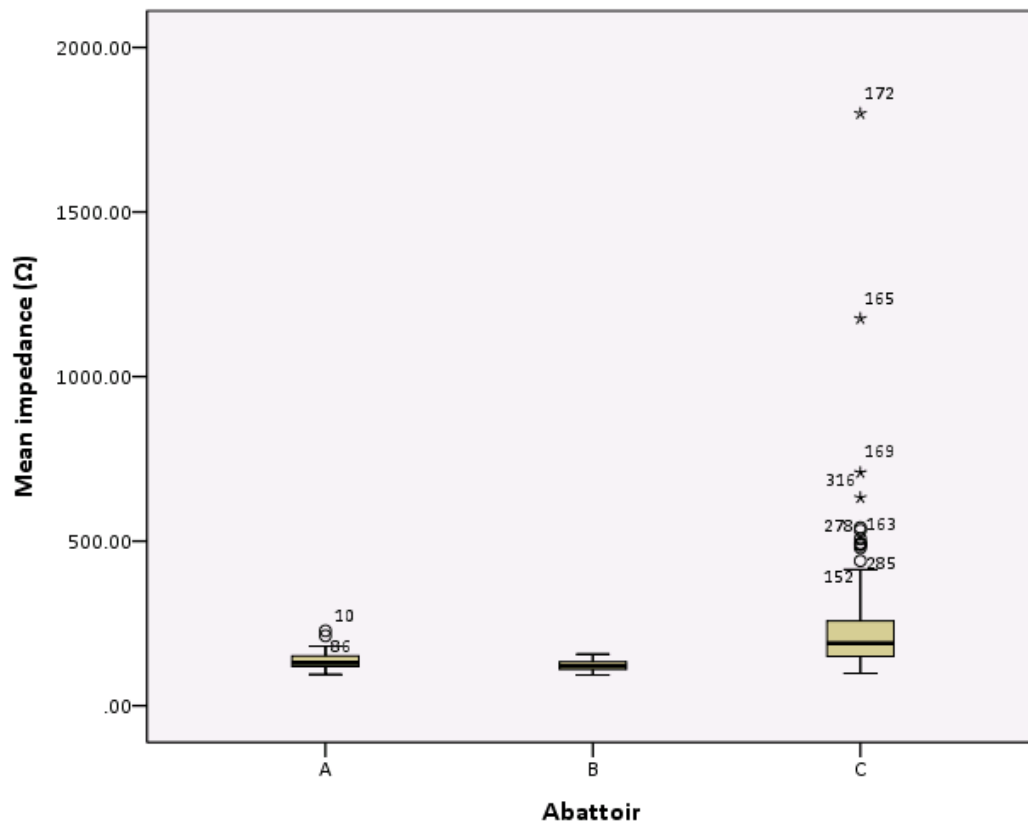
**Figure 3.** Differences in the peak current at 200 milliseconds (ms) between abattoirs, measured in amps (A).



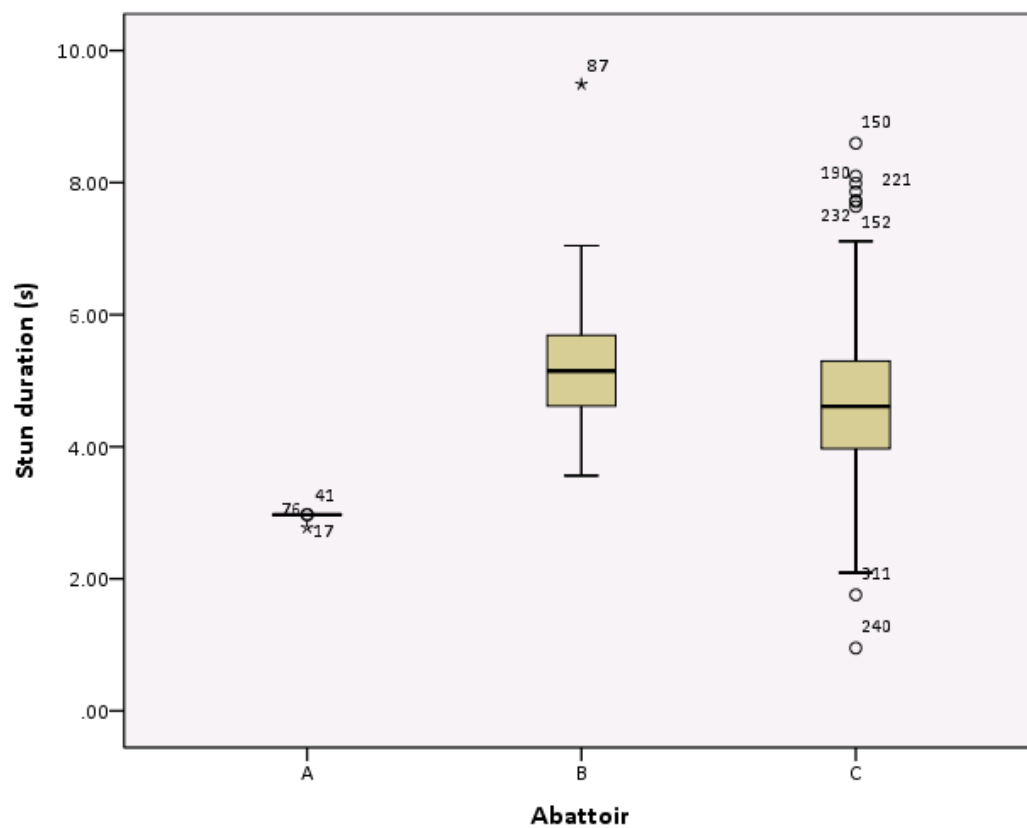
**Figure 4.** Differences in the mean RMS current between abattoirs, measured in amps (A).



**Figure 5.** Differences in the mean RMS voltage between abattoirs, measured in volts (V).



**Figure 6.** Differences in the mean impedance between abattoirs, measured in ohms ( $\Omega$ ).



**Figure 7.** Differences in the stun durations between abattoirs, measured in seconds (s).

**Table 14.** Comparison of the means for peak current at 200 milliseconds (ms), mean RMS current, mean RMS voltage, mean impedance, and stun duration between abattoirs.

	Abattoir			VR	P-value	Sig.
	A	B	C			
	Mean $\pm$ SD					
Peak current at 200 ms (A)	1.05 <sup>a</sup> $\pm$ 0.05	2.49 <sup>b</sup> $\pm$ 0.49	1.26 <sup>c</sup> $\pm$ 0.42	233.16	0.000	***
Mean RMS current (A)	1.02 <sup>a</sup> $\pm$ 0.01	2.14 <sup>b</sup> $\pm$ 0.27	1.43 <sup>c</sup> $\pm$ 0.51	105.99	0.000	***
Mean RMS voltage (V)	139.44 <sup>a</sup> $\pm$ 23.95	255.83 <sup>b</sup> $\pm$ 1.15	274.86 <sup>c</sup> $\pm$ 7.64	2928.64	0.000	***
Mean impedance ( $\Omega$ )	136.39 <sup>a</sup> $\pm$ 23.88	121.65 <sup>a</sup> $\pm$ 15.70	234.49 <sup>b</sup> $\pm$ 167.57	23.97	0.000	***
Stun duration (s)	2.97 <sup>a</sup> $\pm$ 0.02	5.23 <sup>b</sup> $\pm$ 1.01	4.70 <sup>c</sup> $\pm$ 1.15	119.38	0.000	***

A amps, V volts,  $\Omega$  ohms, s seconds

VR variance ratio

\*\*\*P<0.001

Means in a row with the same superscript do not differ significantly.

## 5. Discussion

### 5.1. Effective head-only electrical stunning of sheep

In order for head-only electrical stunning of sheep to be effective from the perspective of animal welfare, it must satisfy two criteria; first, the animals must be rendered immediately unconscious and insensible, and second, they must remain unconscious and insensible until death intervenes usually via exsanguination (Gregory and Wotton, 1985). This study sought to assess the impact of two factors which have been found to affect the effectiveness of head-only electrical stunning of sheep: the electrode position and the presence of wool.

## **5.2. Variations in electrode positions and their impact on the effectiveness of the stun**

Despite the fact that this study only involved three visits to three abattoirs which carry out manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen, it has reinforced the findings of the survey by Anil and McKinstry (1993) of pig abattoirs that, with this particular method of stunning, there can be variations in electrode positions and deviations from the recommended optimum position. While this may not be thought to be good practice, it is not surprising under the circumstances as sheep, in particular, often crowd together when they are within the group in the stunning pen and hide their heads by keeping them low, and also become distressed when they are the last sheep within the group to be stunned due to their isolation from other sheep, therefore making it difficult for the operator to apply the electrodes correctly and consistently.

While such practices are not surprising considering, what is important is, however, that the different positions that are achieved do not compromise the welfare of the animal. This study, by assessing the impact of variations in electrode positions on the effectiveness of the stun, in manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen, has, however, found that, in Abattoir C, the electrode position had a significant impact on the effectiveness of the stun ( $P < 0.05$ ). While only positions 1, between the eye and the base of the ear on each side of the head, and 5, on the nose/jaw, were found to differ significantly, the results clearly show that the stun was more effective when the electrodes were applied in a position that spanned the brain. Position 5, which was the only position that did not span the brain, was found to be the least effective.

As this study assessed the impact of five different electrode positions on the effectiveness of head-only electrical stunning of sheep, it is difficult to compare the findings of this study with the findings of the only similar relevant study on sheep by Velarde *et al.* (2000). This is because, in that study, the impact of only two different electrode positions was assessed, with the positions being frontal, between the eyes and the ears on either side of the head (position 1 in this study), and caudal, behind the ears on the occipital condyle on either side of the head (position 3 in this study). In this study, the impact of position 3 could not be assessed as it was too infrequent, thus the differences between positions 1 and 3 could not be compared like in the study by Velarde *et al.* (2000). What that study did find though was that the frontal position, spanning the brain, was more effective than the caudal.

While the findings of this study cannot be reliably compared to the findings of the study by Velarde *et al.* (2000) on sheep, due to the differences in the number and type of positions, they can be compared to the findings of the study by Anil and McKinstry (1998), even though that study was on

pigs rather than sheep. In the study by Anil and McKinstry (1998), like in this study, the impact of five different electrode positions on the effectiveness of the stun was assessed (positions 1-5 in this study). Despite the fact that in this study, positions 6 and 7 were assessed instead of positions 3 and 4 in the study by Anil and McKinstry (1998), the results of both this study and that study were the same. The effectiveness of the stun was least effective when the electrodes were applied in position 5, on the nose/jaw, and was most effective when the electrodes were applied in a position spanning the brain.

### **5.3. Variations in electrode positions and their impact on the electrical parameters**

This study did not find that the electrode position had any significant impact on the peak current at 200 ms or the mean RMS current in any of the abattoirs (all  $P > 0.05$ ). This was also found in the study by Velarde *et al.* (2000). However, in the study by Anil and McKinstry (1998), it was found that the average current was significantly impacted by the electrode position ( $P < 0.01$ ), with positions 4 and 5 having the lowest average currents. This study also did not find that the electrode position had any significant impact on the mean RMS voltage or the mean impedance in Abattoirs B and C (all  $P > 0.05$ ), but it did have a significant impact on these electrical parameters in Abattoir A (both  $P < 0.01$ ), with position 1 resulting in the lowest mean RMS voltage and mean impedance, and position 6 resulting in the highest.

The electrode position was found to have a significant impact on the mean RMS voltage and the mean impedance in Abattoir A because the type of stunner that they used was different to that used in Abattoirs B and C. In Abattoir A, a constant current stunner was used, whereas in Abattoirs B and C, constant voltage stunners were used. With constant current stunners, the stunner operates at a set current, but the voltage varies with the resistance of the animal's head. The impact of electrode position on the mean RMS voltage and the mean impedance was, therefore, more significant due to the variation in voltage and thus impedance. With constant voltage stunners, on the other hand, the stunner operates at a set voltage and the current varies, hence the variation in voltage and so impedance as a consequence of the electrode position was not as significant.

### **5.4. Wool and its impact on the effectiveness of the stun and on the electrical parameters**

In this study, there was no significant impact of the wool scores on the effectiveness of the stun or on the peak current at 200 ms, the mean RMS current, the mean RMS voltage, or the mean impedance, in any of the abattoirs (all  $P > 0.05$ ). In the study by Velarde *et al.* (2000), however, the effectiveness of the stun was found to be significantly higher ( $P < 0.001$ ) in the animals without wool

in the application sites of the electrodes than in those with wool, and no animals were stunned effectively when the electrodes were applied on wool and dry skin. In the animals without wool, the current was also significantly higher ( $P < 0.05$ ) than in those with wool. In this study, the skin was dry because neither the application sites of the electrodes nor the electrodes themselves were wetted prior to stunning.

### **5.5. Possible reasons for the differences in the effectiveness of the stun between abattoirs**

The effectiveness of stunning was least effective in Abattoir C, as all animals were stunned effectively in Abattoirs A and B. By comparing the electrical parameters in each abattoir, it is clear to see that the quality and consistency of stunning was poorer in Abattoir C. Had the quality and consistency of stunning been the same in Abattoir C as it was in Abattoirs A and B, then it is possible that the electrode position would not have had as much impact on the effectiveness of the stun. One of the most significant differences between Abattoir C and Abattoirs A and B was the mean impedance, with it being significantly higher. It is likely that this was due to poor electrical contact between the electrodes and the skin on the sheep's head. At the time of the visit, it was evident that the electrode design was responsible.

### **5.6. Recommendations for good practice**

In order for manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen to be effective, this study has found that the electrodes must be applied in a position that spans the brain. As discussed earlier, in this method of stunning sheep prior to slaughter, it can be difficult for the operator to apply the electrodes correctly and consistently, because the sheep often crowd together and hide their heads by keeping them low, and also become distressed when they are the last sheep in the group to be stunned. While there may not be anything that can be done to prevent the former, the latter can be prevented by ensuring that no individual sheep are left in isolation in the stunning pen, which can be achieved by making sure that the stunning pen is refilled when there are two or more sheep remaining. Correct and consistent electrode positioning can also be improved by ensuring that the operators are trained and instructed, and that the equipment, especially the electrode design, is effective.

## **6. Conclusions**

To conclude, this study has found that, in order for manual head-only electrical stunning of sheep that are free-standing within a group in a stunning pen to be effective, the electrodes must be applied in a position that spans the brain. There were no significant differences between the positions that span the brain and their impact on the effectiveness of the stun, however, the optimum position is still recommended as in this study this position was found to be associated

with the lowest resistance. Overall, the study has highlighted the issue of variations in electrode positions in this method of stunning sheep prior to slaughter, and has stressed the need for the equipment to be effective, particularly the electrode design.

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